A Draft Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Vernal Pool Depressional Wetlands in Southern California

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ABSTRACT: This Draft Guidebook is an assessment tool that focuses on the functioning of vernal pool wetlands within the Southern Californian eco-region, specifically San Diego County. Its purpose is to provide trained practitioners the means to achieve efficient, reproducible and logical functional assessment results for vernal pool wetlands in San Diego County, California. Results of these assessments can then be used in a variety of ways, such as evaluation of sites for restoration potential, assessment of impacts from existing or proposed projects and monitoring restoration success. Due to the high degree of variability experienced by temporary wetlands in arid climates, we have developed both direct and indirect functional indices for four of the five functions we identified. Direct assessments can only be made when there is sufficient precipitation to elicit the responses that demonstrate function, and we have sought to objectively define "sufficient." Consistent with an HGM approach, use of this Draft Guidebook should be confined to the geographic region and hydrogeomorphic class, subclass and pool types for which it was developed. Use of this methodology outside the boundaries of the reference domain is wholly inappropriate. We are hopeful that our approach can be modified for other pool types within the region, and to vernal pools in other parts of California and Oregon.

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A team effort such as this requires the cooperation and coordination of many individuals with diverse skills and backgrounds. This study was no exception. We set out knowing that we were tackling one of the most—if not the most—difficult wetland ecosystems to characterize, due to its inherent spatial and temporal variability. In southern California, years may pass without sufficient precipitation to elicit the responses of the habitat that are unique to vernal pools: surface and sub-surface water storage, hydrologic connections, biogeochemical processes and active growth of the plant and animal communities.

We are especially appreciative of the work done by Mary Butterwick of the US Environmental Protection Agency, Region IX, on behalf of this project. We recognize her strong commitment to completing this complex and difficult study, her recognition of the importance of a science-based assessment of wetland functions in vernal pools and her work to secure funding and oversee the myriad administrative details. We also thank her for actively participating in the workshops and field-testing phases, and for providing us with her unique expertise related to the wetlands of arid climates. We thank her most especially for her extraordinary patience.

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Forward

The following Draft Guidebook has been partially funded by a wetlands protection state development grant from the U. S. Environmental Protection Agency, Region IX, San Francisco, CA as an assessment tool that focuses on the functioning of vernal pool wetlands within the southern Californian eco-region, specifically San Diego County. The conclusions and opinions contained in this document represent the authors and not the agency. The assessment methodology presented in the Draft Guidebook is based on the Hydrogeomorphic (HGM) approach, one of the most widely accepted reference-based protocols for assessing waters/wetland ecosystem functions in the U.S. This Draft Guidebook follows very closely the format and procedures outlined in documents published by the U. S. Army Corps of Engineers and outlined by the National Action Plan (NAP) to Implement the Hydrogeomorphic Approach (National Interagency Implementation Team, *Federal Register*, 1997).

The purpose of this Draft Guidebook is to allow trained practitioners to achieve efficient, reproducible and logical functional assessment results for vernal pool wetlands in San Diego County, California. Results of these assessments can then be used in a variety of ways, such as evaluation of sites for restoration potential, assessment of impacts from existing or proposed projects and monitoring restoration success. Consistent with an HGM approach, use of this Draft Guidebook should be confined to the geographic region and hydrogeomorphic class, subclass and pool types for which it was developed. Specifically, use of this methodology outside the boundaries of the reference domain is wholly inappropriate. We are hopeful that our approach can be modified for other pool types within the region, and to vernal pools in other parts of California and in Oregon.

Due to the high degree of variability experienced by temporary wetlands in arid climates, we have developed both direct and indirect functional indices for four of the five functions we identified. Direct assessments can only be made when there is sufficient precipitation to elicit the responses that demonstrate function, and we have sought to objectively define "sufficient."

Because it is often necessary to make an assessment under less than ideal conditions, we have also developed protocols for indirect assessment that can be conducted under nearly all conditions and during any season. However, we caution that these indirect assessments provide only a partial and incomplete picture of vernal pool wetland functionality. Depending on the purpose of the assessment, indirect estimates of vernal pool function may be sufficient. However, a full assessment of pool functions necessitates hydrologic conditions (*i.e.*, sufficient precipitation) that can facilitate a more accurate and complete direct functional assessment. Direct assessments will be necessary when endangered species are likely to be present in the proposed Wetland Assessment Area (WAA).

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1 Introduction

Background

The Hydrogeomorphic (HGM) Approach is a collection of concepts and methods for developing functional indices, and subsequently using them to assess a wetland's capacity to perform functions relative to similar wetlands in the region. The approach was initially designed to be used in the context of the Clean Water Act Section 404 Regulatory Program permit review sequence to consider alternatives, minimize impacts, assess unavoidable project impacts, determine mitigation requirements and monitor the success of mitigation projects. However, a variety of other potential applications for the approach have been identified, including comparison of wetland management alternatives or results, identification of priorities for acquisition or set asides, development of design criteria for wetland mitigation or restoration projects, evaluation of the restoration potential of a wetland, and management and monitoring of completed restoration projects (Smith *et al.* 1995).

On 16 August 1996, a National Action Plan to Implement the Hydrogeomorphic Approach (NAP) was published (National Interagency Implementation Team, *Federal Register*, 1997). A National Interagency Implementation Team consisting of the U.S. Army Corps of Engineers (USACE), U.S. Environmental Protection Agency (USEPA), National Resources Conservation Service (NRCS), Federal Highways Administration (FHWA) and U.S. Fish and Wildlife Service (USFWS) cooperatively developed the NAP. Publication of the NAP was designed to outline a strategy and promote the development of Regional Guidebooks for assessing the functions of regional wetland subclasses using the HGM Approach; to solicit the cooperation and participation of Federal, state, and local agencies, academia and the private sector in this effort; and to update the status of Regional Guidebook development.

Development of the regional guidebook for "Vernal Pool Depressional Wetlands in Southern California" was overseen by the US Environmental Protection Agency, Region IX. The guidebook follows the format outlined in the NAP (p. 33612) and explained in various publications of the US Army Corps of Engineers (Brinson 1993, Clairain 2002, Smith 2001, Smith and Wakeley 2001, Smith *et al.* 1995, Wakeley and Smith 2001). The A-Team (Assessment Team) included representatives of local, state and federal agencies, a hydrogeological consulting firm and four academic institutions. The following areas of expertise were represented: hydrogeology, soil science, botany and plant ecology, aquatic vertebrates and invertebrates, population genetics, biogeochemistry and statistics. The group met in San Diego County, California for workshops and fieldwork on three occasions: June 2001, July 2003 and January 2007. Various individuals with private sector biological consulting firms, state and local agencies/jurisdictions and preserve management teams assisted with the fieldwork and provided feedback on elements of the guidebook. Based on the workshops and fieldwork, the regional subclass was defined and characterized, pool types were described, a reference domain was defined, wetland functions were selected, model variables were identified and conceptual models were developed. Each workshop resulted in a refinement of these guidebook elements.

Reference data were collected in 2001, 2002, 2003 and 2007 at a total of 73 reference sites. The data collection periods included a winter with average precipitation, two winters with abnormally low precipitation and one summer following a rainfall year with average precipitation. After each field season, the field protocols were refined and the functions and variables were reviewed and revised. When the data collection was complete, graphical and statistical analytical procedures were used to calibrate the variables and construct FCIs (Functional Capacity Indices) for each wetland function. For purposes of model development and parameterization, we used the reference data collected in 2001 and 2003, and supplemented this with data collected in other, unrelated studies. Data taken in 2002 and 2007 were used to refine field protocols but were not included in model development.

Objectives

The objectives of this Regional Guidebook are to (a) characterize the vernal pool wetlands in southern California south of the Transverse Ranges, (b) present the rationale used to select functions, (c) present the rationale used to select model variables and metrics, (d) present the rationale and analytical techniques used to develop assessment models, (e) provide data from reference wetlands and document their use in calibrating model variables and assessment models and (f) outline the necessary protocols for applying the functional indices to the assessment of wetland functions.

Scope

This guidebook is organized in the following manner. Chapter 1 provides the background, objectives and organization of the guidebook. Chapter 2 provides a brief overview of the major components of the HGM approach and the development and application phases required to implement that approach. Chapter 3 characterizes vernal pool depressional wetlands in southern California in terms of geographical extent, climate, geomorphic setting and soils, hydrology, biogeochemical processes, vegetation, characteristic fauna and other factors that influence wetland function. Chapter 4 discusses each of the wetland functions, model variables and function indices. This discussion includes a definition of the function; a quantitative, independent measure of the function for validation; a description of the wetland ecosystem and landscape characteristics that influence the function; a definition and description of model variables used to represent these characteristics in the assessment model; a discussion of the assessment model used to derive indirect and, if possible, direct indices per function; and an explanation of the rationale and analytical techniques used to calibrate the indices with reference wetland data. Chapter 5 outlines the steps of the assessment protocol for identifying and assessing vernal pool depressional wetlands in southern California. The References (Literature Cited) section follows. Appendix A is a Glossary developed specifically for this Draft Guidebook. Appendix B summarizes the functions, assessment models and variables used in the models. Appendix C includes the forms used for data collection. Appendix D provides supplementary material.

Although it is possible to assess the functions of vernal pool depressional wetlands in southern California using only the information contained in Chapters 4 and 5, it is strongly suggested that users familiarize themselves with the information in Chapters 2 and 3 prior to conducting an assessment.

2 Overview of the Hydrogeomorphic Approach

As reviewed in Chapter 1, the HGM approach is a collection of concepts and methods for developing functional indices and subsequently using them to assess a wetland's capacity to perform functions relative to similar wetlands in a region. The HGM approach includes four integral components: (a) the HGM classification, (b) identification of reference wetlands, (c) assessment models/functional indices and (d) assessment protocols. During the development phase of the HGM approach, these four components are integrated in a Regional Guidebook for assessing the functions of a regional wetland subclass. Subsequently, during the application phase, end users assess the functional capacity of selected wetlands following the Regional Guidebook's assessment protocols. This chapter discusses each component of the HGM approach, and the development and application phases. More extensive discussions of the general approach can be found in Brinson (1993) and Smith *et al.* (1995). Guidelines for the development of guidebooks are contained in Clairain (2002), Smith (2001), Smith and Wakeley (2001) and Wakeley and Smith (2001). A comprehensive glossary of terms that are specific to HGM and vernal pool geology, hydrology and biology is provided at the end of this guidebook.

Hydrogeomorphic Classification

Wetland ecosystems share a number of features, including relatively long periods of inundation or saturation, hydrophytic vegetation and hydric soils. In spite of these common attributes, wetlands occur under a wide range of climatic, geologic, and physiographic settings and exhibit a wide variety of physical, chemical, and biological characteristics and processes (Cowardin *et al.* 1979, Ferren *et al.* 1996, Ferren *et al*. 1996ab, Gosselink and Turner 1978, Mitsch and Gosselink 2000). The variability of wetlands makes it challenging to develop assessment methods that are both accurate (*i.e.*, sensitive to significant changes in function) and practical (*i.e.*, can be completed in the relatively short time available for conducting assessments). Existing "generic" methods designed to assess multiple wetland types throughout the United States are relatively rapid, but often lack the resolution necessary to detect significant changes in function for any specific wetland type. The most logical way to achieve an appropriate level of resolution within the available time frame is to reduce the level of variability in the wetlands being considered by focusing on a more restricted set (Smith *et al.* 1995).

The HGM Classification was developed specifically to accomplish this task (Brinson 1993). It identifies groups of wetlands that function similarly using three fundamental criteria: geomorphic setting, water source, and hydrodynamics. Geomorphic setting refers to the landform and position of the wetland in the landscape. Water source refers to the primary water source in the wetland, such as precipitation, overbank floodwater or groundwater. Hydrodynamics refers to the level of energy and the direction that water moves in the wetland. Based on these three classification criteria, any number of "functional" wetland groups can be identified at different spatial or temporal scales. For example, Brinson (1993) identified five hydrogeomorphic wetland classes at a continental scale. These were later expanded to the seven classes described in Table 2.1 (Smith *et al.* 1995). In many cases, the level of variability encompassed by a continent-wide hydrogeomorphic class is still too great for assessment models that are both rapid to apply and sensitive to functional changes relevant to the 404 review process or other assessment purposes. For example, at a continental scale, the depression class includes wetland ecosystems as diverse as vernal pools in California (Solomeshch *et al.* 2007, Witham *et al.* 1998) and in glaciated forests of the Northeast (Colburn 2004, Calhoun and deMaynadier 2008); prairie potholes in North and South Dakota (Hubbard 1988, Kantrud *et al.* 1989); playa lakes in the high plains of Texas (Bolen *et al.* 1989); huecos, springs and tinajas in Utah and west Texas (Joqué *et al*. 2007, MacKay *et al.* 1990, Vinson and Dinger 2008, Wallace *et al.* 2005); and cypress domes in Florida (Kurz and Wagner 1953).

To reduce both inter- and intraregional variability, the three classification criteria are applied at a smaller, regional geographic scale to identify regional wetland subclasses. In many parts of the country, existing wetland classifications can serve as a starting point for identifying these regional subclasses (Ferren *et al.* 1996, Ferren *et al.* 1996ab, Golet and Larson 1974, Ratliff 1982, Rheinhardt and Hollands 2008, Stewart and Kantrud 1971, Wharton *et al.* 1982). Like the continental classes, regional subclasses are distinguished on the basis of geomorphic setting, water source, and hydrodynamics. In addition, certain ecosystem or landscape characteristics may also be useful for distinguishing regional subclasses in certain regions. For example, depressional subclasses might be based on water source (*i.e.*, groundwater versus surface water) or the degree of connection between the wetland and other surface waters (*i.e.*, the flow of surface water in or out of the depression through defined channels). Tidal fringe subclasses might be based on salinity gradients (Shafer and Yozzo 1998). Slope subclasses might be based on the degree of slope, landscape position, or the source of water (*i.e.*, through flow versus groundwater). Riverine subclasses might be based on water source, position in the watershed, stream order, watershed size, channel gradient, or floodplain width. Examples of potential regional subclasses are shown in Table 2.2 (Smith *et al.* 1995, Rheinhardt *et al.* 1997, Hauer *et al.* 2002).

Table 2.1. Hydrogeomorphic Wetland Classes at a Continental Geographic Scale	
HGM Wetland Class	**Definition**
Depression	Depression wetlands occur in topographic depressions (i.e., closed elevation contours) that allow the accumulation of surface water. Depression wetlands may have any combination of inlets and outlets or may be closed basins that lack them completely. The water source may come from one or any combination of the following: precipitation, overland flow, streams, or groundwater/interflow from adjacent uplands. The predominant direction of flow is from the higher elevations toward the center of the depression, but may come from a deep aquifer, or subsurface springs. The predominant hydrodynamics are vertical fluctuations that range from diurnal to seasonal. Depression wetlands may lose water as evapotranspiration, through intermittent or perennial outlets, or as recharge to groundwater. Prairie potholes, playa lakes, vernal pools, and cypress domes are common examples of depression wetlands.
Tidal Fringe	Tidal fringe wetlands occur along coasts and estuaries and are under the influence of sea level. They intergrade landward with riverine wetlands where tidal current diminishes and river flow becomes the dominant water source. Additional water sources may be groundwater discharge and precipitation. The interface between the tidal fringe and riverine classes is where bidirectional flows from tides dominate over unidirectional ones controlled by floodplain slope of riverine wetlands. Because tidal fringe wetlands frequently flood and water table elevations are controlled mainly by sea surface elevation, tidal fringe wetlands seldom dry for significant periods. Tidal fringe wetlands lose water by tidal exchange, by overland flow to tidal creek channels, and by evapotranspiration. Organic matter normally accumulates in higher elevation marsh areas where flooding is less frequent and the wetlands are isolated from shoreline wave erosion by intervening areas of low marsh. Spartina alterniflora salt marshes are a common example of tidal fringe wetlands.
Lacustrine Fringe	Lacustrine fringe wetlands are adjacent to lakes where the water elevation of the lake maintains the water table in the wetland. In some cases, these wetlands consist of a floating mat attached to land. Additional sources of water are precipitation and groundwater discharge, the latter dominating where lacustrine fringe wetlands integrade with uplands or slope wetlands. Surface water flow is bidirectional, usually controlled by water-level fluctuations resulting from wind or seiche. Lacustrine wetlands lose water by flow returning to the lake after flooding and evapotranspiration. Organic matter may accumulate in areas sufficiently protected from shoreline wave erosion. Unimpounded marshes bordering the Great Lakes are an example of lacustrine fringe wetlands.
Slope	Slope wetlands are found in association with the discharge of groundwater to the land surface, or at sites with saturated overland flow with no channel formation. They normally occur on sloping land ranging from very gentle to steep. The predominant source of water is groundwater or interflow discharging to the land surface. Direct precipitation is often a secondary contributing source of water. Hydrodynamics are dominated by downslope unidirectional water flow. Slope wetlands can occur in nearly flat landscapes if groundwater discharge is a dominant source to the wetland surface. Slope wetlands lose water primarily by saturated subsurface flows, surface flows, and by evapotranspiration. Slope wetlands may develop channels, but the channels serve only to convey water away from the slope wetland. Slope wetlands are distinguished from depression wetlands by the lack of a closed topographic depression, and the predominance of the groundwater/interflow water source. Fens are a common example of slope wetlands.

continued

Table 2.1. *(concluded)* **Hydrogeomorphic Wetland Classes at a Continental Geographic Scale**	
HGM Wetland Class	**Definition**
Mineral Soil Flats	Mineral soil flats are most common on interfluves, extensive relic lake bottoms, or large floodplain terraces where the main source of water is precipitation. They receive virtually no groundwater discharge, which distinguishes them from depressions and slopes. Dominant hydrodynamics are vertical fluctuations. Mineral soil flats lose water by evapotranspiration, overland flow, and seepage to underlying groundwater. They are distinguished from flat upland areas by their poor vertical drainage due to impermeable layers (e.g., hardpans), slow lateral drainage, and low hydraulic gradients. Mineral soil flats that accumulate peat can eventually become organic soil flats. They typically occur in relatively humid climates. Pine flatwoods with hydric soils are a common example of mineral soil flat wetlands.
Organic Soil Flats	Organic soil flats, or extensive peatlands, differ from mineral soil flats, in part because their elevation and topography are controlled by vertical accretion of organic matter. They occur commonly on flat interfluves but may also be located where depressions have become filled with peat to form a relatively large flat surface. Water source is dominated by precipitation, while water loss is by overland flow and seepage to underlying groundwater. They occur in relatively humid climates. Raised bogs share many of these characteristics but may be considered a separate class because of their convex upward form and distinct edaphic conditions for plants. Portions of the Everglades and northern Minnesota peatlands are common examples of organic soil flat wetlands.
Riverine	Riverine wetlands occur in floodplains and riparian corridors in association with stream channels. Dominant water sources are overbank flow from the channel or subsurface hydraulic connections between the stream channel and wetlands. Additional water sources may be interflow or occasional overland flow from adjacent uplands, tributary inflow, and precipitation. When overbank flow occurs, surface flows down the floodplain may dominate hydrodynamics. In the headwaters, riverine wetlands often intergrade with slope or depressional wetlands as the channel (bed) and bank disappear, or they may intergrade with poorly drained flats or uplands. Perennial flow is not required. Riverine wetlands lose surface water via the return of floodwater to the channel after flooding and through surface flow to the channel during rainfall events. They lose subsurface water by discharge to the channel, movement to deeper groundwater (for losing streams), and evapotranspiration. Peat may accumulate in off-channel depressions (oxbows) that have become isolated from riverine processes and subjected to long periods of saturation from groundwater sources. Bottomland hardwood floodplains are a common example of riverine wetlands.

Table 2.2. Potential Regional Wetland Subclasses in Relation to Geomorphic Setting, Dominant Water Source and Hydrodynamics				
Geomorphic Setting	**Dominant Water Source**	**Dominant Hydrodynamics**	**Potential Regional Wetland Subclasses**	
			Eastern USA	**Western USA/Alaska**
Depression	Groundwater, precipitation or interflow	Vertical	Prairie potholes, marshes, Carolina bays	Vernal pools
Fringe (tidal)	Ocean	Bidirectional, horizontal	Chesapeake Bay and Gulf of Mexico tidal marshes	San Francisco Bay marshes
Fringe (lacustrine)	Lake	Bidirectional, horizontal	Great Lakes marshes	Flathead Lake
Slope	Groundwater	Unidirectional, horizontal	Fens	Avalanche chutes
Flat (mineral soil)	Precipitation	Vertical	Wet pine flatwoods	Large playas
Flat (organic soil)	Precipitation	Vertical	Peat bogs, portions of Everglades	Peatlands over permafrost
Riverine	Overbank flow from channels	Unidirectional, horizontal	Bottomland hardwood forest	Riparian wetlands
Adapted from Smith *et al*. 1995 and Rheinhardt *et al*. 1997.				

Reference Wetlands

Reference wetland sites are selected in the HGM development process to represent the range of variability that occurs in a regional wetland subclass as a result of natural processes and disturbances (*e.g.*, succession, channel migration, fire, erosion and sedimentation), as well as cultural alteration. The reference domain is the geographic area occupied by the reference wetlands (Smith *et al.* 1995). Although the geographic extent of the reference domain should reflect the geographic area encompassed by the regional wetland subclass, this is not always possible because of time and resource constraints.

Reference wetlands serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of function across the suite of functions selected for a regional wetland subclass. Second, they establish the range and variability of conditions exhibited by model variables and provide the data necessary for calibrating model variables and assessment models. Finally, they provide a concrete physical representation of wetland ecosystems that can be observed and measured.

Following accepted HGM practice, reference standard wetlands are typically defined to be the subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least-human-altered wetland sites in the least-human-altered landscapes. Table 2.3 outlines the terms as commonly used by the HGM approach in the context of reference wetlands.

Table 2.3. Reference Wetland Terms and Definitions (Smith *et al*. 1995)

Term	**Definition**
Reference Domain	The geographic area from which reference wetlands representing the regional wetland subclass are selected.
Reference Wetlands	A group of wetlands that encompass the known range of variability in the regional wetland subclass resulting from natural processes and disturbance and from human alteration.
Reference Standard Wetlands	The subset of reference wetlands that perform a representative suite of functions at a level that is both sustainable and characteristic of the least human altered wetland sites in the least human altered landscapes. By convention, the functional capacity index for all functions in reference standard wetlands are assigned a 1.0.
Reference Standard Wetland Variable Condition	The range of conditions exhibited by model variables in reference standard wetlands. By convention, reference standard conditions receive a variable subindex score of 1.0.
Site Potential (mitigation project context)	The highest level of function possible given local constraints of disturbance history, land use, orother factors. Site potential may be less than or equal to the levels of function in reference standard wetlands of the regional wetland subclass.
Project Target (mitigation project context)	The level of function identified or negotiated for a restoration or creation project.
Project Standards (mitigation context)	Performance criteria and/or specifications used to guide the restoration or creation activities toward the project target. Project standards should specify reasonable contingency measures if the project target is not being achieved.

By definition, HGM guidebooks assign all functions in reference standard wetlands a Functional Capacity Index (FCI) of 1.0. However, this treatment of "the best wetlands in the reference domain" leads to conflicts between the principles behind the HGM approach, calibration of specific HGM models and unbiased application of HGM to a diversity of sites. Specifically:

1. It is usually impossible to fit a statistical FCI model with actual field data that yields the same fitted FCI as an *a priori* FCI. (In other words, r^2 for the statistical model is < 1.0). Thus, *a priori* FCI values of 1.0 that have been assigned to reference standards in any particular function can only be approximated with real data. This is true for both direct FCI estimates, and indirect FCI estimates, with greater departures generally found with indirect FCIs. Other HGM

guidebooks generally circumvent this problem by using simple FCI models with only a few variables, so that all reference standard wetlands will in fact receive a score of 1.0 for the function. However, the FCI models are not fitted to actual data in many guidebooks. When they are fitted to real data, the wetlands chosen often do not represent the full range of natural variability and anthropogenic disturbance. In this guidebook, we consider the difference between *a priori* FCI scores and fitted FCI scores to be error in the statistical model. We attempted to minimize these errors using standard statistical techniques, but in most cases we chose not to simplify the models to the extent necessary to completely eliminate them. Thus, application of this guidebook is not expected to yield the maximum score of FCI = 1.0 for all undisturbed wetlands in all cases.

2. A deeper philosophical issue arises with regard to the definition of "function." Assigning a value of 1.0 to all functions for all reference standard wetlands implies that the functional capacity is not being estimated on an absolute scale. Consider a shallow vernal pool at the headwaters of a pool network, with a relatively small catchment area. Even in an unaltered landscape, such a pool may only fill during the wettest years. In a typical year, it may store no surface water and very little subsurface water. What *a priori* value should it be assigned for the function "Surface and Sub-surface Water Storage"? There are four options:

a. Assign an undisturbed headwater pool an *a priori* FCI < 1.0 for water storage because, despite its pristine nature, it stores very little water in absolute terms. However, it may be assigned a score of 1.0 for other functions. Redefine the term "reference standard" in a manner that departs from other guidebooks (Table 2.3), and include this pool as a reference standard.

b. Do not classify it as a reference standard, based on the traditional reference standard definition. We suspect that most or all other HGM guidebooks have taken this approach, and omitted undisturbed wetlands from the reference standard class if their hydrology, biota or other attributes are atypical or depauperate.

c. Such a pool could be included as a reference standard and assigned an *a priori* FCI of 1.0 for water storage. This makes model fitting difficult, with at least three options:

i. The FCI can be fitted using a simple model based on *absolute* amount of water stored. However, for undisturbed headwater pools to receive a value of 1.0, the model would need to be so lenient that nearly all pools would receive a value of 1.0.

ii. The FCI can be fitted using a complex and more realistic model based on *absolute* amount of water stored. Reference standard headwater pools would almost certainly receive very low scores in the fitted model, leading to unacceptably high model error.

iii. A preferred route may be to fit the FCI using a realistic model based on the amount of water stored *relative to important covariates*. Examples of such covariates would include maximum depth, landscape position and underlying soil type. In the above example, the fitted FCI would perhaps have different scales for shallow vs. deep pools, or headwater vs. terminal pools in a network. Field application of the model to new pools would not assess “How much water is stored”, but rather “How much water is stored, relative to reference standard pools with the same depth and landscape position.”

If one accepts the premise that “function” should be estimated in relative terms, rather than absolute, option c) iii) is clearly defensible. However, accurate model fitting would require collecting data from multiple reference pools across the full spectrum of covariates. It would likely require data from many years that span the full range of precipitation events. As mentioned above, we suspect that previous HGM wetland guidebooks have focused exclusively on pools that have typical values for covariates such as hydroperiod, landscape position and depth, excluding those that have more extreme values (Gilbert *et al*. 2006).

d. One could designate shallow headwater pools as unscorable for the water storage function based on insufficient data for model calibration. They could still be retained as reference standards if all other functions that can be scored are given an *a priori* FCI of 1.0. If new data are gathered in the future, the function could be revised using one of the other options.

In this guidebook, we generally strived to incorporate approach c) iii), and opted for approach d) in cases where insufficient field data were available for accurate model calibration.

Assessment Models and Functional Indices

In the HGM approach, an assessment model is a simple representation of a function performed by a wetland ecosystem. It defines the relationship between one or more characteristics or processes of the wetland ecosystem. Functional capacity is simply the ability of a wetland to perform a function compared to the level of performance in reference standard wetlands.

Model variables

Model variables represent the characteristics of the wetland ecosystem and surrounding landscape that influence the capacity of a wetland ecosystem to perform a function. Model variables are ecological quantities that consist of five components (Schneider 1994): (a) a name,

(b) a symbol, (c) a measure of the variable and procedural statements for quantifying or qualifying the measure directly or calculating it from other measures, (d) a set of values (*i.e.*, numbers, categories, or numerical estimates: Leibowitz and Hyman 1997) that are generated by applying the procedural statement, and (e) units on the appropriate measurement scale. Table 2.4 provides several examples.

Table 2.4. Components of a Model Variable

Name (Symbol)	Measure/Procedural Statement	Resulting Values	Units
Basin Depth ($V_{MAXDEPTH}$)	The maximum depth of the pool, as estimated with surveying equipment.	>0	meters
Inlet Modification ($V_{INLETMOD}$)	Discernible modification to the inlet.	0 = no 1 = yes	unitless
Coverage of Basin with Cobbles ($V_{COBBLESBA}$)	The percent cover of the basin surface with angular coarse pebbles or cobbles, as defined in the 1993 USDA Soil Survey Manual.	0 to 100	percent, written as a whole number

Model variables occur in a variety of states or conditions in reference wetlands. For example, percent herbaceous groundcover could be large or small. Based on its condition (*i.e.*, value of the metric), model variables are usually assigned a variable subindex by rescaling them. A variable subindex of 1.0 is often assigned when the condition of a variable is within the range exhibited by reference standard wetlands. As the condition declines from that found in reference standard wetlands, the variable subindex is assigned based on the relationship between model variable condition and functional capacity. In most cases, the rescaling of variables into variable subindices is based on pertinent literature, personal expertise and experience and information from reference wetlands (Smith *et al.* 1995). Lower subindex values reflect decreasing contributions to functional capacity, relative to reference standard wetlands. In some cases, the variable subindex can drop to zero. The rationale for intermediate subindex scores is generally less well defined, although a linear relationship is usually assumed between the original variable's value and the subindex value. For this guidebook, we only assigned subindex scores to the Hydrologic Networks function. For the other three functions for which data were collected, we used statistical analyses to relate the relative contributions each variable made to the function via equation coefficients (see below and Chapter 5). For these functions, the model fitting was accomplished without first scaling each variable to a maximum of 1.0. In the end, the difference between the two approaches is not important, since the score assigned to a particular pool would be the same either way.

In the HGM approach, model variables are combined into an assessment model to produce a Functional Capacity Index (FCI) that ranges from 0.0 to 1.0. Within each function, the variables are usually combined as a simple average. However, we used a statistical model for most functions, in which the coefficient for each variable is derived from a multiple regression or general linear model. The FCI is a measure of the functional capacity of a wetland relative to reference standard wetlands in the reference domain. Wetlands with an FCI of 1.0 perform the function at a level characteristic of reference standard wetlands. As the FCI decreases, it indicates that the capacity of the wetland to perform the function is less than that of reference standard wetlands. In some cases, the FCI may be based on model variables that directly relate to the function of the variable, and can only be assessed under specific field conditions (*e.g*., when the pool is holding water). In this guidebook, we refer to these as Direct FCIs. Alternatively, the FCI may be based on variables that can be measured at any time of the year, correlate well with the level of function, but are *not causally related* to the function. We refer to these as Indirect FCIs.

Conceptual Framework for Computing Direct and Indirect FCIs Using Graphical and Statistical Analyses

For all but the Hydrologic Networks function and Biogeochemical Processes function, we employed both exploratory and formal graphical and statistical analyses to determine how single variables and groups of variables relate to the function. Details of our approach are provided in Chapter 5 in the section titled "Analytical Techniques and Procedures." We included interactions among variables when they emerged from the analysis and could be explained by known processes. We searched for threshold effects and other nonlinear relationships between the variables and the level of function. Ultimately, we discarded many variables that did not have explanatory power both empirically and logically.

As a first step in developing an FCI based on direct measures of function (*i.e.,* a Direct FCI), we developed guidelines for assigning an *a priori* FCI to each pool. The *a priori* FCI generally describes the overall level of function for a vernal pool based on best expert opinion. The subset of pools deemed to be reference standards (i.e., the most functional representations of natural vernal pools) received an *a priori* FCI of 1.0 for all functions (see extended discussion in Reference Wetlands above). However, we neither expected nor enforced the assumption that non-reference standard pools should have identical FCI scores for all functions. For example, disturbances that severely alter the hydrology of a particular vernal pool may have less impact on its fauna than its water storage capacity. To maintain objectivity, we developed verbal definitions for seven different FCI values ranging between 0.0 and 1.0 (see Appendix D.6). FCI guidelines similar to those in Appendix D.6 have not been made explicit in any other HGM guidebook.

The targets for application of this HGM guidebook are all vernal pools within the reference area, rather than those that provide the maximum *absolute* level of functionality for all functions. Therefore, we addressed the full array of variability encountered in the field, including pools that pond rarely because they are high in the landscape, have small contributing watersheds and/or are shallow. Whenever possible, consideration of these attributes has been included within the Direct and Indirect FCIs. For example, the FCIs for the faunal community cannot be scored for very shallow pools (< 0.07 m) due to an absence of data for calibration, and they include different criteria for moderately shallow pools (0.07 m ≤ max. depth < 0.15 m) vs. deep pools (max. depth ≥ 0.15 m). In all respects, the development of the statistical models (the Direct FCI and the Indirect FCI) was heavily weighted on the reference standard pools and those pools that were the least functional. Scores for the Direct and Indirect FCIs were constrained to be as close as possible to the *a priori* FCI scores for the reference standards (where *a priori* FCI = 1.0) and the least functional pools (where *a priori* FCI ≤ 0.25). This follows the general approach of previous guidebooks, where the intent is to base initial development of the statistical FCI model on the "best" and "worst" pools in the reference area.

For all functions, a general linear model was used to predict the Direct FCI (dependent variable) from a linear combination of categorical and/or continuous variables that clearly relate to the specific function. We would characterize the exploratory data analysis used to arrive at this general linear model as extremely thorough. For each of the functions, all univariate relationships between the field data and the *a priori* FCI were examined both graphically and statistically, and scores of alternative multivariate models were evaluated and compared. After arriving at a single statistical model *(i.e.*, a preliminary Direct FCI), we then validated and calibrated it on the full set of pools that had been sampled for that function (see Table 5.8 for sample sizes).

To accommodate variables that can be measured in the field at any time of year (even when pools are dry), Indirect FCIs were also developed for each function. We calibrated each Indirect FCI on its corresponding Direct FCI using all available pools. Similar to development of the Direct FCIs, we derived Indirect FCIs using exploratory data analysis, examination of all univariate relationships and analysis of a very large number of general linear models with multiple dependent variables. However, development of the Indirect FCI differed in three fundamental ways. First, the dependent variable in the Indirect FCI analyses was the final calibrated Direct FCI. Second, all pools for which field data had been taken were used in the Indirect FCI derivation. (In contrast, the Direct FCI was developed using the *a priori* FCI as the dependent variable and only the most and least functional pools in the first steps.) Third, the set of possible independent variables in the Indirect FCI statistical models was restricted to those that can be measured at any time during the year. (The Direct FCI targeted independent variables that were causally related to the function, even if they could only be measured when a vernal pool is in its wet phase.) By design, the Indirect FCI is a more rapid and convenient way to assess pool function than the Direct FCI, and the Indirect FCI may be calculated at any time of year. However, this convenience comes at the cost of reduced accuracy.

Assessment protocols

The final component of the HGM approach is the assessment protocol. The assessment protocol is a series of tasks, along with specific instructions, that allow the end user to assess the functions of a particular wetland area using the functional indices in the Regional Guidebook. The first task is characterization, which involves describing the wetland ecosystem and the surrounding landscape, describing the proposed project and its potential impacts, and identifying the wetland areas to be assessed. The second task is collecting the data for model variables. The final task is analysis, which involves calculation of functional indices. Chapter 5 provides detailed instructions for site characterization and data collection necessary for development of Direct and Indirect FCIs.

Development Phase

An interdisciplinary team of experts known as the "Assessment Team," or "A Team" ideally carries out the Development Phase of the HGM approach. A team of 5-8 individuals is recommended as sufficiently large to represent critical disciplines and not too large as to be unwieldy (Smith *et al.* 1995). The following disciplines have been recommended for representation on the "A Team": wetland ecology, geomorphology, biogeochemistry, hydrology, soil science, plant ecology and animal ecology.

The product of the Development Phase is a Regional Guidebook for assessing the functions of a specific regional wetland subclass (Figure 2.1). In developing a Regional Guidebook, the A-Team completes the following major tasks. After organization and training, the first task of the A-Team is to classify the wetlands within the region of interest into regional wetland subclasses using the principles and criteria of the HGM Classification (Brinson1993, Smith *et al.* 1995). Next, focusing on the specific regional wetland subclasses selected, the A-Team develops an ecological characterization or functional profile of the subclass. The A-Team then identifies the important wetland functions, conceptualizes assessment models, identifies model variables to represent the characteristics and processes that influence each function, and defines metrics for quantifying model variables. Next, reference wetlands are identified to represent the range of variability exhibited by the regional subclass. Field data are then collected from the reference wetlands and used to calibrate model variables and verify the conceptual assessment models. Finally, the A-Team develops the assessment protocols necessary for regulators, managers, consultants and other end users to apply the indices to the assessment of wetland functions.

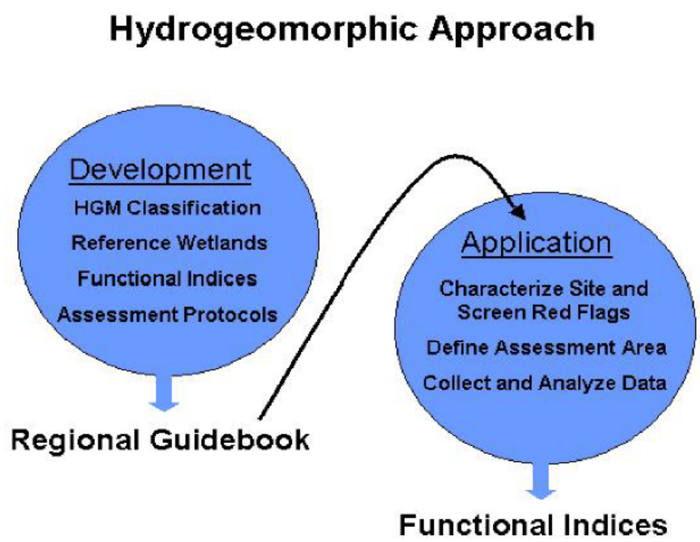

Figure 2.1. Development and application phases of the HGM approach.

The following list provides the detailed steps involved in this general sequence:

Task 1: Organize the A-Team.

a. Identify A-Team members.

b. Train A-Team in the HGM approach.

Task 2: Select and Characterize Regional Wetland Subclasses.

a. Identify/prioritize wetland subclasses.

b. Select regional wetland subclasses and define reference domain.

c. Initiate literature review.

d. Develop preliminary characterization of regional wetland subclasses.

Task 3: Select Model Variables and Metrics and Construct Conceptual Assessment Models.

a. Review existing assessment models.

b. Identify model variables and metrics.

c. Define initial relationship between model variables and functional capacity.

d. Construct conceptual assessment models for deriving FCIs.

e. Complete Precalibrated Draft Regional Guidebook (PDRG).

Task 4: Identify and Collect Data from Reference Wetlands.

a. Identify reference wetland field sites.

b. Collect data from reference wetland field sites.

c. Analyze reference wetland data.

Task 5: Calibrate and Field Test Assessment Models.

a. Calibrate model variables using reference wetland data.

b. Verify and validate (optional) assessment models.

c. Field test assessment models for repeatability and accuracy.

d. Revise PDRG based on calibration, verification, validation (optional), and field-testing results into a Calibrated Draft Regional Guidebook (CDRG).

Task 6: Conduct Peer Review and Field Test of CDRG.

a. Distribute CDRG to peer reviewers.

b. Field test CDRG.

c. Revise CDRG to reflect peer review and field test recommendations.

d. Distribute CDRG to peer reviewers for final comment on revisions.

e. Incorporate peer reviewers' final comments on revisions.

f. Publish Operational Draft Regional Guidebook (ODRG).

Task 7: Technology Transfer.

a. Train end users in the use of the ODRG.

b. Provide continuing technical assistance to end users of the ODRG.

Application Phase

The Application Phase involves two steps. The first is to use the assessment protocols outlined in the Regional Guidebook to carry out the following tasks (Figure 2.1).

a. Define assessment objectives.

b. Characterize the project site.

c. Screen for red flags.

d. Define the Wetland Assessment Area.

e. Collect field data.

f. Analyze field data.

The second step involves applying the results of the assessment (*i.e.*, the FCIs), to the appropriate decision-making process. Although the HGM approach was originally conceived for use in a regulatory context as part of Section 404 of the Clean Water Act, it has a variety of other potential applications. For instance, the HGM assessment models for southern Californian vernal pools were developed primarily for use in ecosystem restoration and preserve management, within an overall planning context. There are several ways in which the HGM approach can be applied as part of an overall planning framework. For instance, in analysis of alternative plans, it can be used to measure variable impacts to existing wetlands, or locate and evaluate potential restoration sites. Because the HGM approach produces numerical values as a measure of various wetland functions, these numbers can be used to quantify and compare impacts and benefits to wetlands due to various alternative proposed plans and actions. It can similarly be used to evaluate the effectiveness of management practices and suggest corrective actions.

3 Characterization of the Temporary and Seasonally Ponded Vernal Pool Ecosystems in Southern California

Regional Wetland Subclass and Reference Domain

This Draft Regional Guidebook was developed to assess the functions of depressional, rainfed, temporarily and seasonally ponded herbaceous wetlands in California south of the Transverse Ranges, and from the Peninsular Ranges west to the Pacific Ocean. These pools are commonly called vernal pools in recognition of the seasonality of the habitat and the springtime floral display (Purer 1937, Ramaley 1919). This guidebook should also be used on sites that formally had vernal pools but now lack some or all of these characteristics.

Vernal pools are found throughout California in many geographic settings and subclimates (Keeler-Wolf *et al.* 1998, Figure 3.1). Due to statewide variation in geomorphology, soil profiles and climate, pools have a wide range of hydrological regimes and substrates that support a diverse and locally adapted flora and fauna. The ecosystem is known for endemism and abundant speciation within many plant and animal genera (*e.g*., Simovich 1998, Stebbins 1976), and some endemic pool species have extremely restricted distributions (Bauder and McMillan 1998, Griggs and Jain 1983, King 1998, Ornduff 1976, Simovich 1998, Stebbins 1976).

Within the regional subclass of southern Californian vernal pools, there are 24 possible types based on classification by geomorphologic origin and age (See Chapter 5, Table 2). We have identified pools in 16 cells of the matrix. The reference domain selected to represent this regional wetland subclass included only 5 pool types: coastal mesa/pedogenic (Mira Mesa/Miramar and Otay Mesa), inland valley/pedogenic and alluviated (Ramona), coastal mesa/landslide (Otay Mesa) and inland valley alluviated (Ramona) (Figure 3.2). Under ideal circumstances, the reference domain would have encompassed all of the known pool types and different areas within types. Given the region's immense area (about 15 million acres) and extreme year-to-year variation in precipitation, resources were not available to include all pool types under conditions suitable for assessment. It is hoped that the methodology and analytical techniques developed for the reference domain will be expanded to other pool types within the regional subclass and to other areas of California as well. The pedogenic vernal pools of San Diego County are in many ways intermediate in properties such as soil depth and leakage rates through the resistant, pool-supporting horizons, allowing some extrapolation to other pool types that we could not measure.

Our approach was developed specifically to deal with the assessment challenges presented by the seasonality of the wetlands and the highly variable climate.

(Source: California Wetlands Information System, http://ceres.ca.gov/wetlands/geo_info/vernal_pools_map.html)

Figure 3.1. Vernal pool regions in California.

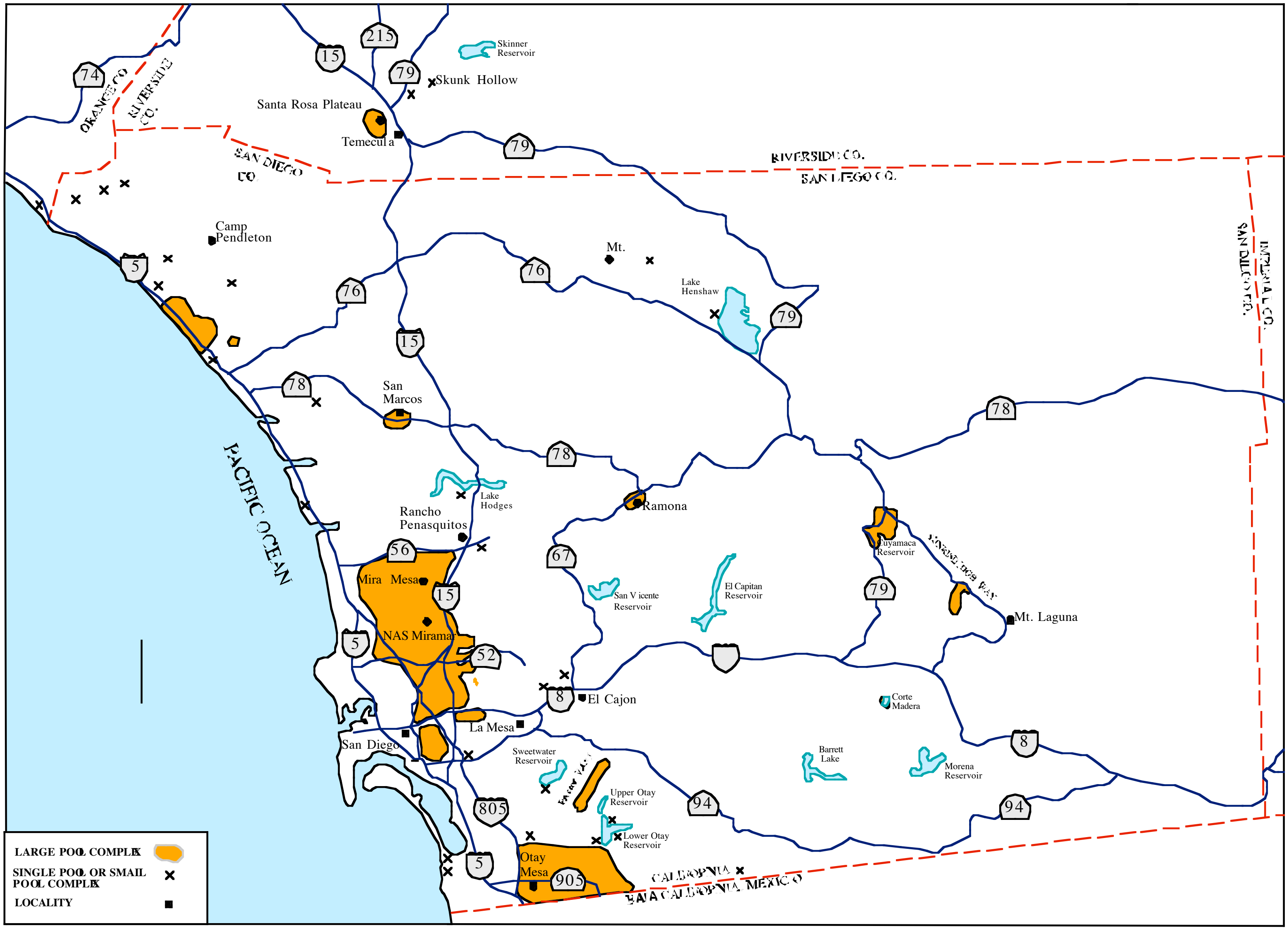

Figure 3.2. Area containing reference pools.

Description of the Regional Wetland Subclass

Vernal pools occur on alluvial or marine terraces and various volcanic substrates (Bauder and McMillan 1998, Holland and Dains 1991, Keeler-Wolf *et al.* 1998, Norwick 1991). Although some may be isolated or approach the size of small lakes (Bauder *et al.* 1998, Lathrop 1976), they are more commonly found in archipelagoes of small ponds situated in depressions among soil mounds or hummocks, connected by a directional network of swales or shallow drainages. Clayey surface soils in the basins are often underlain by a hardpan of cobbles cemented with a combination of iron and silica or, less frequently, by granitic or basaltic rocks that prevent percolation of water into the subsoil (Nikiforoff 1941, Weitkamp *et al.* 1996). The region's Mediterranean climate brings winter rainstorms—often intense—followed by a long summer drought. After the rains begin, pools form in the depressions above the poorly draining soil layer or layers. When they are filled to capacity, their surface area ranges from as small as 50 ft^2 to 20 acres. Vernal pools can remain filled for 3-5 months during wetter years, but may fail to pond water in years of sparse precipitation. Fluctuating water levels during the rainy season can expose and re-inundate the soil surface of pool basins a number of times before they dry completely in late spring. Large pools with a substantial watershed may occasionally retain water year round. Within- and between-year variability in moisture conditions is the crucial factor preventing these wetlands from becoming freshwater marshes or persistent ponds, or from being dominated by upland shrubs and herbs.

Climate

In southern California, climatic variables are most influenced by distance from the coast, topography and elevation (Bauder and McMillan 1998). Yearly average precipitation is lowest along the coast and rises with distance inland, to a peak in the Peninsular Ranges to the east (Table 3.1). It then drops abruptly in the rain shadow of the mountains where the upper Sonoran Desert (Colorado Desert) begins. Long-term means are 8.5-13 inches at coastal locations and 24-49 inches in the mountains. Within a rainfall year (July 1 to June 30), most of the precipitation occurs from November through March and is concentrated in a half dozen storms that may occur within a few months or be spread more evenly over the rainfall season (Bauder 2005, Goldman *et al.* 1986, Mooney and Parsons 1973). Precipitation is greater than potential evapotranspiration (ET_0) only during the winter months (Greenwood 1984, Greenwood and Abbott 1980). At higher elevations to the east, rain from summer convective storms may produce up to 20 percent of the yearly precipitation during the June-August period (Bauder 1994), and a significant portion of the yearly precipitation in the mountains may fall as snow. In the mountains, below freezing temperatures often occur between October/November and April/May (Bowman 1973). On the coastal terraces there is little or no frost.

Table 3.1. Climatic Variables Affecting Vernal Pools and Temporary Lakes in Southern California.

Pool Location		Elevation # (feet)	Annual Precipitation* (inches)
Coastal Mesas	Chula Vista	56	10.9
	La Mesa	530	12.8
	Montgomery Field	414^	13.1
	Otay Mesa	510^	10.5
	Oceanside Harbor	10	10.5
	Laguna Beach~	60	12.7
	Santa Barbara~	14	14.1
Inland Mesas	Santa Rosa Plateau+	2,400	15.0-16.6
Inland Valleys	El Cajon, Gillespie Field (west)	380^	10.7
	El Cajon (east)	520^	14.1
	Ramona	1,450	16.1
	San Marcos	520^	12.6
	Perris~	1470	10.4
	Moorpark~	58	13.1
Mountains	Cuyamaca	4,640	38.7
	Palomar	5,550	49.4

Elevation from NOAA Climatological Data, Station Index; otherwise, from USGS 7 1/2 minute quadrangle maps (^).

* Precipitation from County of San Diego (Cartographic Services) rainfall map and WRCC~.

\+ All data from Lathrop and Thorne, 1976.

As with all arid and semi-arid climates, annual variability in precipitation is substantial (Le Houérou 1984). Since record keeping began in the City of San Diego in 1850, yearly precipitation at the Lindbergh Field weather station has ranged from 2.03 inches in 2001/2002 to 25.98 inches in 1883/84. Over a l03-year period at Cuyamaca in the inland mountains, precipitation has ranged from a 13.46 inches to 74.65 inches. Very dry or wet years can follow each other, with no obvious temporal autocorrelations (Bauder 1987a, Bauder 2005).

The inland valleys share characteristics of both the montane and coastal climates, with precipitation higher and frost more common than along the coast, but snow and summer rainfall rare. Although the valleys lie on the coast-to-mountain continuum, anomalies in topography may greatly affect their climate. Cold air often drains through canyons into low-lying valleys, and minor rain shadows can develop as a result of adjacent mountains and hills. For example, El Cajon Valley has occasional frost and lower rainfall than nearby La Mesa, which is situated on the coastal terrace. Although the mean annual precipitation for La Mesa is 12.81 inches, the western end of the El Cajon Valley (in the shadow of Mount Helix and Fletcher Hills) has a mean of 10.71 inches (Cartographic Services, County of San Diego). Three miles further inland, the mean at the east end of the valley increases to 14.13 inches (Bauder and McMillan 1998).

Geomorphic setting and soils

The primary landscape positions of vernal pools in southern California are mesas or valleys. Pools near the coast in San Diego County occur on marine-influenced terraces distributed in a broad arc west of the mountains known as the San Diego embayment (Kennedy 1975). The embayment was geologically active during the Pleistocene Epoch, with sea levels rising and falling numerous times, resulting in wave-cut terraces that were exposed or submerged, depending on the sea level. Many of the inland valleys are filled with granitic alluvium, but weathered sandstone and leucocratic (light-colored) volcanic rocks contributed to the surfaces.

Virtually all soils maps for Southern California are prepared at a scale emphasizing mapping areas larger than 20 to 40 acres (Order 3). Soils within the pools themselves are not mapped; rather, they are considered 'inclusions' which may or may not be discussed in the soil survey texts. Differences between the inclusion and the local soils are least for pedogenic soils and greatest for landslide-related soils. The upland soil series associated with vernal pools all have phases that share similar properties: 1) slopes of 9% or less, 2) a thick clay layer in the B horizon beginning approximately 1-2 feet below the upland soil surface that retards drainage and 3) low permeability, often <0.06 inches per hour, which is the slowest class used by soil scientists.

Within the reference domain, the soil series differ in their origins, distributions and other properties such as pH (Table 3.2). Chesterton, Redding, Olivenhain and Murrietta are acidic in both the surface and subsurface layers. Placentia, Stockpen and Huerhuero soils are acidic at the surface but have alkaline subsurface layers. Willows is alkaline in both the surface and subsurface layers. With the exception of the Placentia and kindred soils, all of the cismontane soil series supporting vernal pools were subject to past marine influences. Chesterton, Huerhuero and Stockpen soils developed from sandy marine sediments. Redding and Olivenhain soils were formed on cobbly alluvium cut from an Eocene alluvial fan by rising Pleistocene sea levels and deposited on wave-cut terraces. They subsequently were exposed in late Pleistocene times. Placentia soils formed in granitic alluvium found in small- to medium-size inland valleys. The likelihood of pools having once been present on the smaller patches of Placentia soils is low, and to our knowledge there are no documented occurrences in these minor drainages.

Table 3.2.
Southern California Soil Series within which Vernal Pools Are Reported[1]

SOIL SERIES	SYMBOL of MAPPING UNIT	SYMBOL (urbanized)	TYPE OR TEXTURE OF LOW-PERMEABILITY LAYER[2]	DEPTH OF LO-PERM LAYER (inches)	PERMEABILITY (in/hr)	pH (surface/subsurface)	REPRESENTATIVE POOL LOCATIONS
ALTAMONT	AtC		clay & clay loam	0-36	.06-0.20	6.6/8.0	San Marcos ?
ARLINGTON	AvC		weakly cemented coarse sandy loam	33-48	.06-0.20	6.7/6.5	Ramona ?
AULD	AwC		clay	0-54	.06-0.20	6.8/7.8	San Marcos ?
BONSALL	BlC,BlC2, BmC, BnB		heavy clay loam	10-38	<0.06	6.2/8.0	Ramona ?
BOSANKO	BsC, BtB		clay & sandy clay loam	0-30	.06-0.20	6.3/8.2	Alpine ? Ramona ?
CALLEGUAS	CaF (w/ LeE2)		shaly loam	0-20	0.63-2.0	7.4/8.4	Simi/Moorpark (Tierra Rejada)[3] ?
CARLSBAD*	CbC, CbB	CcC	weakly cemented hardpan	39-50	<.06	6.0/6.5	Miramar Landfill, W series pools;
							San Onofre State Beach
CHESTERTON	CfB, CfC	CgC	sandy clay, cemented hardpan	19-34,34+	<.06	6.0/5.2	coastal mesas?
CHINO	Ce		no distinct layer		.20-.63	7.9/8.4	Hemet-upper Salt Crk
CIENABA	141,142		Sandy loam	0-7; 0-17	2.0 to 6.0	5.6/7.3	Chiquita Ridge (part)
CLAYEY ALLUVIAL	Co		clay, clay loam		slow		Ramona ?
CLEAR LAKE	CeC		clay	0-62	0.06-0.20	7.5/7.9	Simi/Moorpark (Tierra Rejada)[3]
CROPLEY	149		clay	0-65	.06-0.20	6.6/8.4	Costa Mesa
DIABLO	DaC	DcD	clay	0-32	.06-.2	6.8/7.8	Otay Mesa ?
HUERHUERO*	HrC, HrC2	HuC	clay and clay loam	12-55	<.06	5.3-/8.2	coastal mesas and Marron Valley
JAMES CANYON^	JcA, JcD		loam	none indicated	0.6-2.0	6.8/6.8	Cuyamaca Valley
LAS FLORES	LeC, LeC2	LfC	sandy clay	14-38	<.06	5.8/6.8	San Marcos? Pendleton?
LAS POSAS	LpB, LpC, LpC2		clay and clay loam	0-33	.2-.63	7.3/6.8	
LINNE	LsE		clay loam	0-37	.2-.63	7.9/8.1	Simi/Moorpark (Tierra Rejada)[3] ?
LOAMY ALLUVIAL	Lu						SD County mountains
MYFORD	172			12-49	<.06	5.1-8.4	Costa Mesa, San Clemente State Beach
MURRIETTA*	MuE		clay	9-17	.06-0.20	5.6/6.0	Santa Rosa Plateau (Mesas de Burro &
							Colorado, Mesa de la Punta & Redonda Mesa)
OLIVENHAIN*	OhC	OkC	very cobbly clay loam & clay	10-42	<.06	5.7/5.3	coastal mesas
PLACENTIA*	PeC, PeA, PeC2,		sandy clay	13-34	<.06	6.0/8.0	San Marcos, Ramona
	PfA, PfC						
RAMONA	RaA, RaB, RaC, RaC2		sandy clay loam	17-72	.2-.63	6.2/6.8	Ramona? San Marcos?
REDDING*	RdC, ReE	RhC	gravelly clay & indurated hardpan	15-30,30-45	<.06	5.8-4.5	central coastal mesas
SALINAS	SbA, SbC, ScA, ScB		clay	0-46	.06-0.20	7.2/7.9	?
SHINGLETOWN^			loam	10-20	.06-0.20	6.0/6.7	Cuyamaca Valley
SOPER	201,204		gravelly clay loam	8 to 21	0.2 to 0.6	6.1/7.8	Chiquita Ridge (part);
							also, nearby Radio Tower Ridge
STOCKPEN*	SuA, SuB		gravelly clay, clay	21-60	<.06	6.5/8.0	Otay Mesa
TRAVER	Ts		none		6.3-20.0	6.6/7.8	Hemet-upper Salt Crk

[1] Virtually all soils maps for Southern California are prepared at a scale emphasizing mapping areas larger than 20 to 40 acres (Order 3).
Soils within the pools themselves are not mapped; rather, they are considered 'inclusions' which may or may not be discussed in the soil survey texts.
Differences between the inclusion and the local soils are least for pedogenic soils and greatest for landslide-related soils.

[2] Adapted from the soil series description and/or tables describing engineering properties and classifications, engineering test data or physical and chemical properties of soils.

[3] The 4.6-acre pool at Tierra Rejada is part of a 5 to 10 acre area of low slopes on which the soil appears to be Clear Lake clay, not the Calleguas or Linne steep-slope soils that occur on either side of this tectogenic trough (Hecht et al., 1998); hence Clear Lake clays are included in this table.

* = vernal pool soil types in which most Southern California pools occur.
^ = not contained in USDA soils maps for San Diego County (Borst 1984).
? = co-occurrence of soils and pools unknown or uncertain.

Sources: USDA Soil Surveys for San Diego (Bowman 1973), Orange and Western Part of Riverside (Wachtell 1978) and Santa Barbara (Cole *et al*. 1958, Shipman 1981) Counties and Ventura (Edwards *et al*. 1970) and Western Riverside (Knecht *et al*. 1971) areas; Bomkamp 1995; Bramlet 1996; RECON 1995; Riefner & Pryor 1996; and Hecht *et al*. 1998.

In addition to the accumulated (or "illuviated") clays, some pool soils are also underlain by a more impervious hardpan or bedrock beneath the drainage-retarding clay layers. These substrates can range from cemented hard pans composed of cobbles held together by iron and silica cement (as in the Redding soils) to calcic cementation or to granitic and volcanic bedrock. Their role in vernal pool hydrology is essentially unknown. These deeper substrates are clearly not necessary to the formation of pools, although in some cases they may be the primary factor (*e.g.*, Hidden Lake on Mount San Jacinto and the Santa Rosa Plateau in Riverside County). Some of the larger pools in Riverside and Ventura Counties are formed along faults, where tectogenic pools have evolved in sags or topographic lows initially established (or maintained) by faulting. Many pools underlain by marine shales in Orange and San Diego are often formed in pull-away depressions at the heads of very large landslides of probable Pleistocene age. Thick accumulations of clay characterize both these pond types, which have one of the slowest seasonal responses due to the large cracks and heavy clays that must respond to the initial rains of winter before ponding can occur (Hecht *et al.* 1998). These two pool types receive a higher volume and proportion of entering clay particles, which accumulate at rates that exceed the cementation rates of the pedogenic-pool soils.

The majority of pools found in San Diego County occur (and historically were found) on Redding soils. Profiles typical of this soil series are represented in Figure 3.3 (Soil Survey Laboratory 1996). At the site level, the gradient in Redding soil texture from uplands to the lowest elevations of the basin is striking, with the clay fraction increasing with depth (Figure 3.4; Bauder 1987a). Various soil chemistry variables are likewise correlated with position on the upland/basin elevational gradient (Table 3.3; Bauder 1987a). Number of days inundated has a strong negative correlation with elevation and is positively associated with the presence of several nutrients (Table 3.3; Bauder 1987a).

Hydrology

<u>Water sources</u>

All water in vernal pools originates as precipitation. Principal sources for all pool types are rainfall directly onto the pool surface, as well as surface runoff and subsurface inflow from near-pool areas (seldom more than 5 to 10 pool diameters away except in the wettest of years). In the alluviated pools of Ramona and other areas, overflow from adjoining streams can contribute to the pool, or the pools may develop as part of the stream system, bringing in water from more than a mile distant in some cases. Dune-dammed pools and landslide-head pools may also receive surface inflow from a channel with a watershed of several acres or perhaps slightly more. In many cases, pools pond before the surrounding soils are saturated. When this occurs, water may move

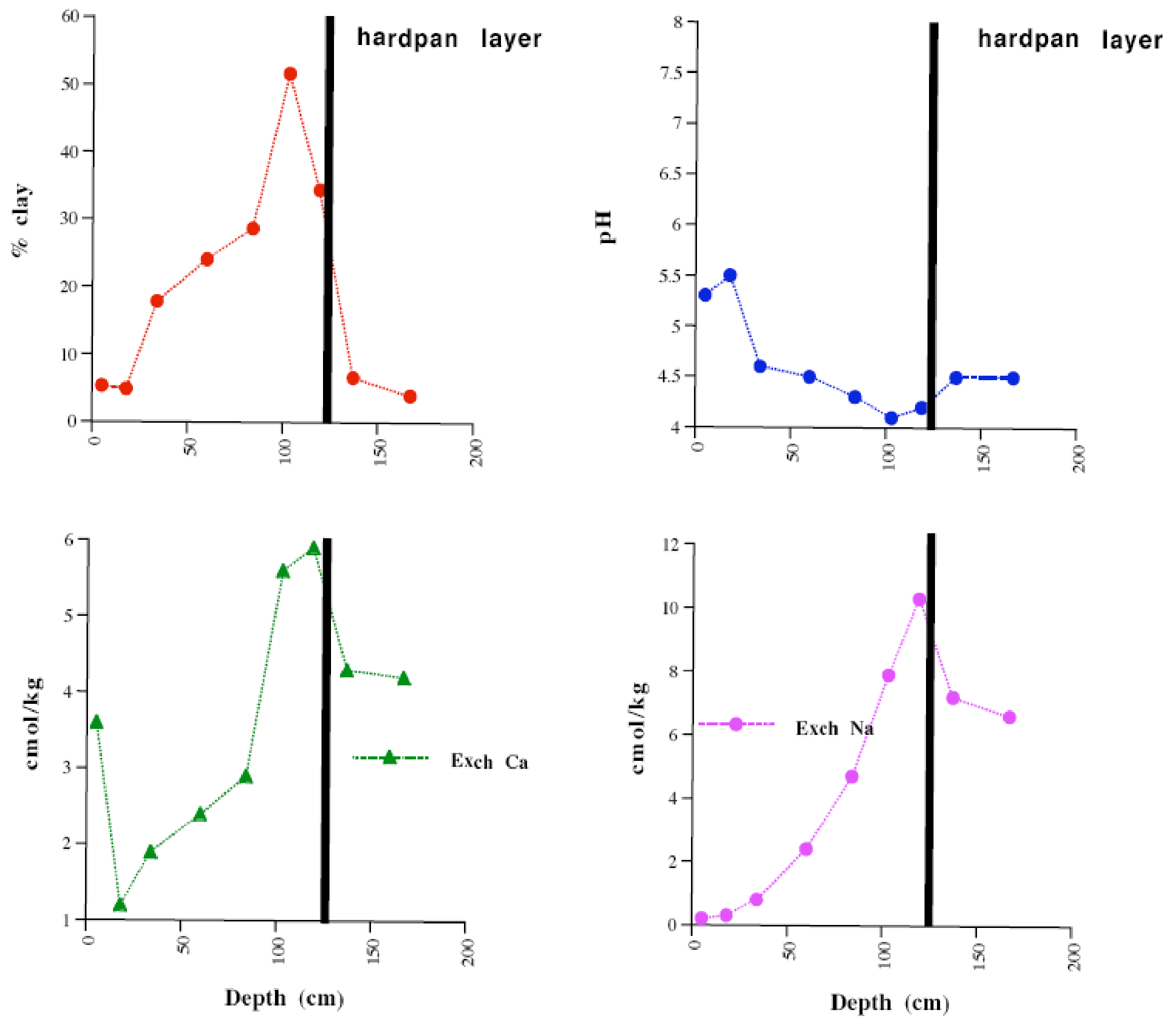

Figure 3.3. Redding soil series profile (Soil Survey Laboratory 1996).

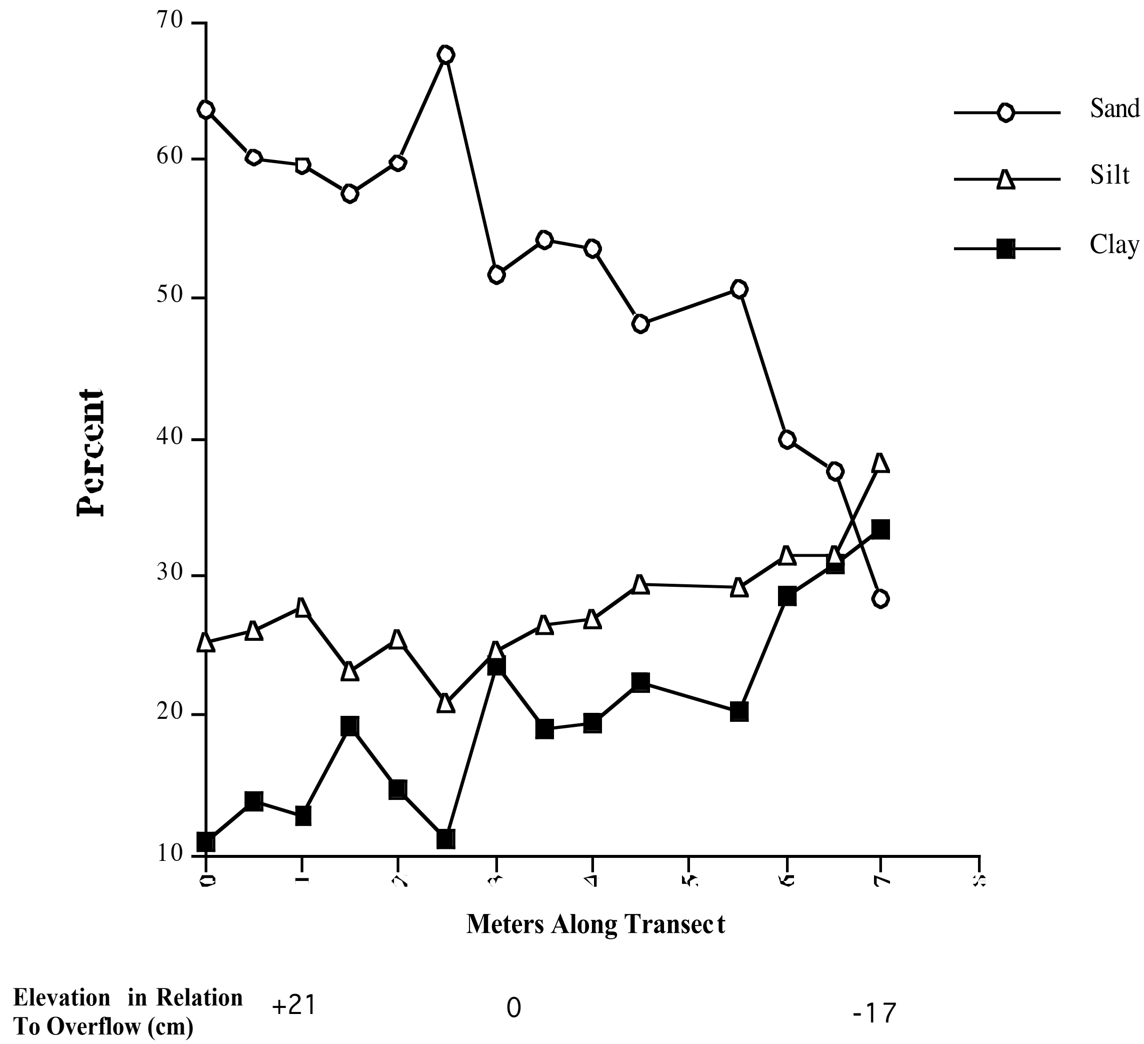

Figure 3.4. Soil texture fractions in relation to elevation in a San Diego vernal pool on Redding soils (Bauder 1987a).

Table 3.3.
Relationship Between Soil Nutrient Concentrations and Elevation, and Between Soil Nutrient Concentrations and Duration of Ponding

NUTRIENT	ELEVATION (cm)	WATER DURATION (days)
TKN~	.311**	.232*
NH4	.215*	0.19
NO3	.491***	.592***
PO4	.322**	.465***
Na+	.479***	.484***
Ca++	0.041	0.076
K+	0.122	0.125
Mg++	.443***	.715***

Entries are Pearson correlation coefficients. Soil samples were taken every other dm along transects spanning the upland/pool basin gradient (n = 87). Elevation was measured as the vertical distance above or below pool overflow. Water duration is the maximum total number of days each dm^2 quadrat was inundated during the 1982/1983 rainfall season.
Length of inundation was calculated for each dm^2 quadrat sampled.
~Total Kjeldahl nitrogen

*, ** and *** indicate significance at the 0.05, 0.01 and .0001 levels, respectively.
Source: Bauder 1987a

from the pool into the surrounding soils, reversing direction later in the season. Shallow-water inflow from the 'contributing area' can be substantial during years of abundant rainfall, extending the ponding duration.

Recent work in northern California (Rains *et al.* 2006, Rains *et al.* 2008) has shown that parent geology of the soils strongly affects the manner in which water moves into and out of the soils. Applied to southern California, this work suggests a fundamental difference between perched surface-water systems in clay-rich soils, such as those developed on marine shales or in tectogenic and landslide pools, and the pedogenic (or 'hardpan') pools derived primarily from granitic or volcanic parent materials, which are a combination of surface-water and perched ground-water systems. The clay-rich soils have much higher salinities, with sodium as a predominant cation, while the pedogenic pools of granitic or volcanic origin[1] (such as those in Redding soils) have a more dilute cation suite dominated by calcium. Primary productivity in the

[1] Some of the pedogenic pools developed on marine shales or other sediments in the San Diego area have properties intermediate between the clay-rich and granitic/volcanic pools.

clay-rich pools is often constrained by nitrogen, while phosphorus tends to be the nutrient limiting productivity in most pedogenic pools. Alluviated and bedrock pools of southern California are most likely to share the hydrochemical properties of most pedogenic soils, while dune-dammed pools will be more similar to the clay-rich pools. Rains and colleagues note that although they are morphologically similar, pool types differ by physical and chemical hydrology, and therefore "should be treated differently in resource conservation, restoration, and management efforts." (Rains *et al.* 2008)

Hydrodynamics

Once filled, pools hold water for varying durations. Early in the season, movement of water into the adjoining soils can rapidly lower pool levels, especially during the first few hours after storms. Later in the year or following major storms, water flowing into the pond from the adjoining soil can gradually increase water levels after a rainfall event ends. Deeper pools pond longer (Shaw *et al.* 2006, Brooks and Hayashi 2002). They tend to draw subsurface inflow from a larger area that replaces water lost by evapotranspiration but also lose water to shallow groundwater via infiltration (Brooks and Hayashi 2002). In San Diego County vernal pools, the duration of ponding increases by 4.5 days for each 0.1 foot (3.04 cm) of measured maximum depth (Shaw *et al.* 2006). Landscape position likewise affects the likelihood of ponding and the length of ponding events. Pools may be isolated or part of a network. A network is an integrated set of channels and basins that drain a watershed. Basins within a network will function hydrologically in accordance with their position within the network, the size of the watershed and the antecedent and incident rainfall (Figure 3.5). Pool salinities often reach a minimum during the middle of the winter season. Early ponding events dissolve salts left on the bed and banks of the pool by the prior season's evaporation, or those brought into coastal pools as aerosols. Salinities gradually decrease later in the season as shallow ground water enters the pools. Later in spring, salinities increase rapidly as the pools desiccate (*cf.*, Napolitano and Hecht 1991, Rains *et al.* 2008) (Figure 3.6).

Biogeochemical processes

Vernal pool biogeochemistry is largely controlled by hydrological processes (Boon 2006). As indicated above, precipitation is the water source for southern Californian vernal pools as it falls directly on the basin, moves through the surface and subsurface soil and enters via surface flow. Spatial and temporal characteristics of the hydrodynamics affect the frequency, depth and duration of inundation that in turn determine the nature and extent of the biogeochemical processes (Boon 2006). Wetlands such as raised, hydrologically isolated ombrotrophic bogs that receive all of their moisture from precipitation are nutrient poor (*i.e.*, oligotrophic). Rock pools may also be nutrient

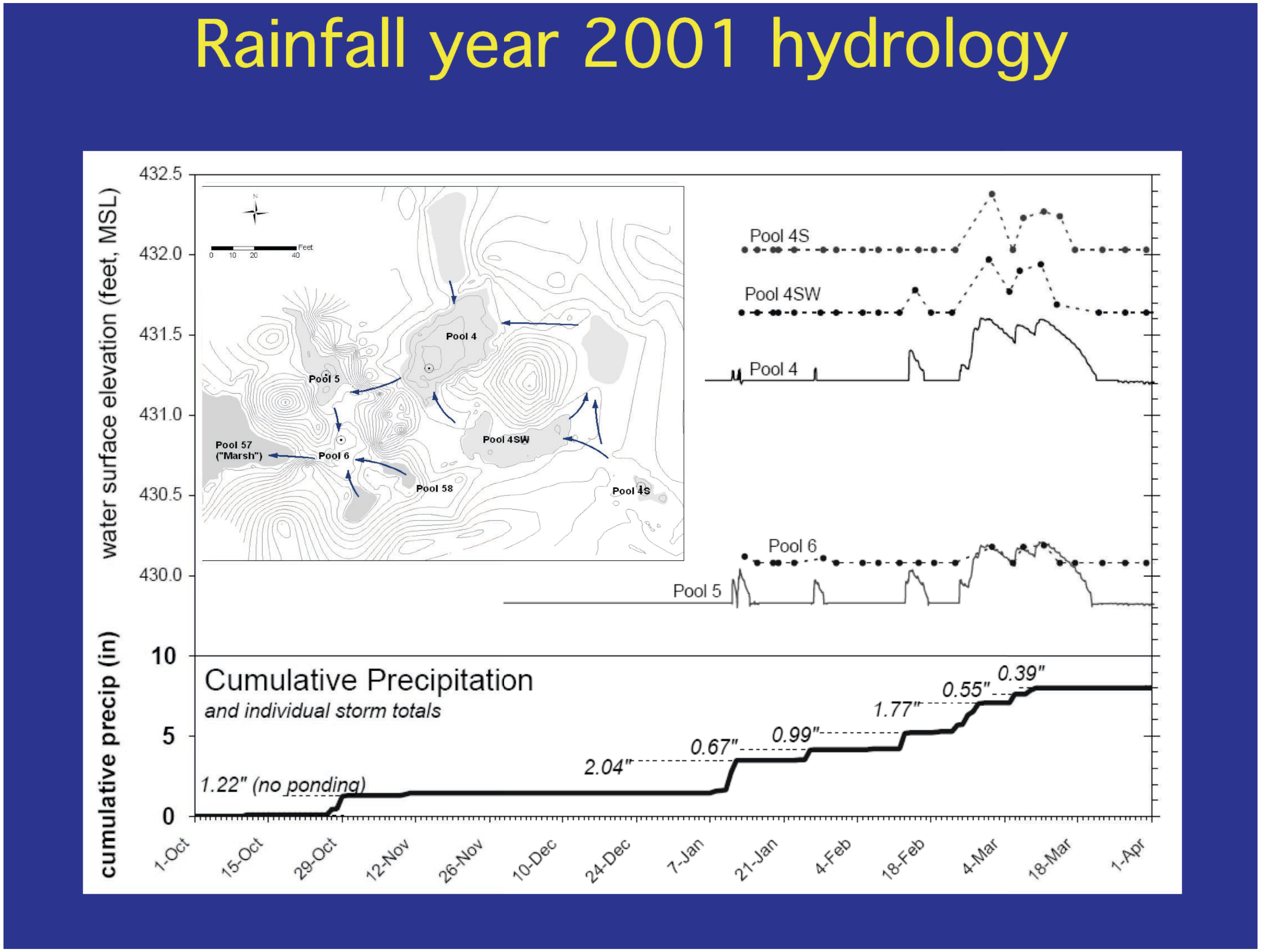

Figure 3.5. Cumulative precipitation and progressive ponding in a network of pools.

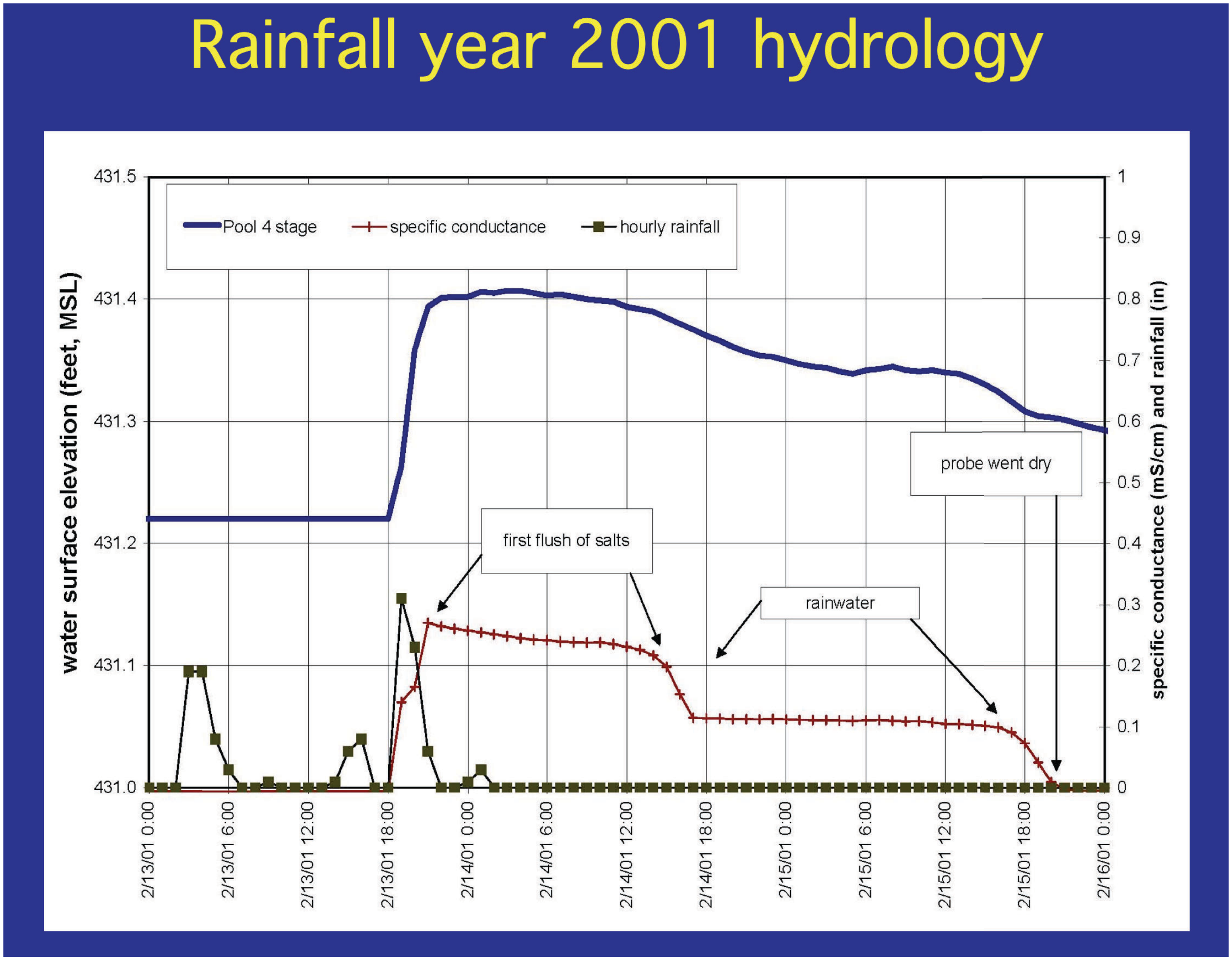

Figure 3.6. Seasonal progression of specific conductance.

poor due to the lack of soil development in their watersheds (Joqué *et al*. 2007). Vernal pools are rain-fed, and in southern California receive little precipitation, even for a Mediterranean climate (Table 3.1). In general, they are surrounded by nutrient-poor soils and large nutrient accumulations in woody shrubs and dead biomass and litter (McMaster *et al*. 1982, Rundel and Vankat, 1989) making their low nutrient levels and water chemistry similar to "…oligotrophic lacustrine habitats found at higher elevations and latitudes." (Keeley and Zedler 1998)

Surface flows are infrequent in southern Californian vernal pool networks due to the region's aridity and unpredictable precipitation patterns. When they do occur, flowpaths are important because they control water-sediment contacts and contact times. Flowpaths vary depending upon underlying geology (Rains *et al.* 2006, Rains *et al.* 2008, Weitkamp *et al.* 1996). Clay-rich soils have low infiltration rates, so infiltration-excess overland flow typically is the dominant flowpath even during low-intensity storms (Rains *et al.* 2006, Rains *et al.* 2008). In studies of claypan vernal pools in northern California, water remained on the surface while moving rapidly toward local topographic lows occupied by vernal pools. Conversely, in nearby pool landscapes on hardpan soils with high infiltration rates at the surface and low infiltration rates in the shallow subsurface, shallow groundwater flow typically is the dominant flowpath even during high-intensity rainfalls (Rains *et al.* 2006, Rains *et al.* 2008). In these cases, water remains in the subsurface while moving slowly toward local topographic lows occupied by the vernal pools (Hanes and Stromberg 1998). Over a 2-year period, Weitkamp *et al.* (1996) studied water movement from the upper-slope soils to the footslope in a group of 10 large pools underlain by basaltic-topped mesas. At the footslope, downward movement was slowed, due to a sharp change in soil texture. Water began to accumulate first at the footslope/pool edge, and the basin soils followed after the pool edge became saturated. Surface soils at the toeslope and in the basin were rich in clay (> 40%) and those of the backslope and footslope contained < 20 and 30% clay, respectively.

Rapid overland flow can erode and transport sediments and organic carbon from the surface of the uplands to the vernal pools, where sediments release adsorbed phosphorus and organic carbon dissolves and contributes to the *in-situ* stocks of dissolved organic carbon (Rains *et al.* 2008). Shallow groundwater flow can dissolve and transport silica and nitrate from the subsurface of the uplands to the vernal pools, allowing ample time for dissolved organic carbon (DOC) to be adsorbed to the iron oxides in the upland soils (Rains *et al.* 2006, Rains *et al.* 2008). Differential transport and accumulation of minerals also occurs in bedrock pool systems (Weitkamp *et al.* 1996). In simple terms, the manner in which surface water is delivered to vernal pools is the primary determinant of initial water chemistry. Rapid overland flow typically yields high phosphorus and DOC concentrations, and relatively low silica and nitrogen concentrations.

Shallow groundwater flow is characterized by relatively high silica and nitrogen concentrations, and relatively low phosphorus and DOC (Rains *et al.* 2008).

As discussed above (Hydrology: Water Sources and Hydrodynamics), water also moves into and out of the immediately adjacent upland soils over the course of the rainy season (Hanes and Stromberg 1998, Napolitano and Hecht 1991). This provides additional nutrient inputs and affects the concentration of salts and other constituents of the pool water.

Timing of water movement is important because of the asynchrony between hydrological and biological processes in Mediterranean-type climates (Tate *et al.* 1999, Holloway and Dahlgren 2001, Rains *et al.* 2006). In the dry season, annual species senesce but microbial activity continues, nitrogen is mineralized, and nitrate accumulates in upland soils. During early-season storms (usually late fall), there is little biological demand for this nitrate, so it is readily dissolved and transported to vernal pools. This nitrate is largely flushed in the early wet season. During late-season storms, there is high biological demand on the remaining nitrate, so there may be little remaining nitrate to be dissolved and transported to the vernal pools. As a result, early-season storms may produce relatively large flushes of nitrate while late-season storms may produce little more than water.

Position in a network of pools and individual pool basin morphology are important factors affecting pool biogeochemistry. Joqué *et al*. (2007) found that shallow rock pools in Utah had higher temperatures and percent oxygen, greater turbidity and lower concentrations of nutrients compared to deeper, persistent pools lower in the watershed. We found pools higher in the network were the last to fill (Figure 3.5 and Chapter 4 Hydrologic Networks function), and in drier years do not fill at all (Bauder unpublished data). The depth and structure of the surface soil profile and the type and percentage of clay affect water storage capacity, soil pore sizes, movement of oxygen and water, heat capacity, adsorption of cations and surface cracking.

Algae are important primary producers in wetland ecosystems, but aquatic food webs are predominantly detrital, and bacteria are the most important of the secondary producers (Boon 2006). They dominate the uptake and release of nutrients and dissolved organic matter in wetlands (Boon 2006). Bacteria, fungi and actinomycetes depolymerize cellulose, releasing glucose that is used by a wide array of heterotrophic soil microbes. Various specialized members of the soil microbial community produce enzymes that mineralize nutrients. Root exudates are an important source of carbon, as well as other organic substrates that are readily degradable by soil microbes. The rhizosphere supports larger populations of bacteria (both ammonifying and denitrifying), actinomycetes (Gram positive bacteria) and other soil microbes compared to surrounding soils, although clayey soils show more modest differences (Bannister 1976, Russell 1977).

In southern California, vernal pools may dry and re-pond up to 6 or 7 times within one rainy season. Alternating episodes of wetting and drying promote the loss of gaseous nitrogen from the soils (Boon 2006). Repeated episodes of soil drying and wetting affect the soil microbial fauna. Bacteria, yeasts, fungi and actinomycetes differ in their tolerance of water stress, with bacteria the most sensitive and actinomycetes the least (Killham 1994). The bacterial community can respond to alternating aerobic and anaerobic periods as short as 2 days (Boon 2006). There may be flushes of nutrients due to the release of intracellular solutes when soil microbes adjust cell solutes to changing moisture conditions (Boon 2006, Killham 1994). However, review of the research on the effects of drying and rewetting indicates that soil microbes do not produce a net liberation of nutrients into the water column, nor do they accelerate organic-matter decomposition or leaf litter breakdown (Boon 2006). Some soil animals such as protozoa and rotifers that need soil pores for locomotion can be particularly affected by the sealing of soil cracks and pores during hydration of shrink/swell clay soils and by the drying out of the soil pore spaces during dry interludes in the rainy season.

Vernal pools are biogeochemically distinct from the surrounding uplands. They are inundated for many days or even months annually, and are often densely covered with annual grasses, forbs and pool-bed algae. The surrounding uplands are never inundated, and are characterized by moderate coverage with shrubs and/or annual grasses, aerobic soils and relatively low productivity. Therefore, vernal pools are islands of mesic, often anaerobic soils and relatively high productivity in a matrix of xeric, aerobic soils and relatively low productivity. Though comparative data are lacking, it is likely that these conditions result in nutrient uptake in vernal pools being greater than nutrient uptake in surrounding uplands. A study in Australia found that during wet periods, temporary wetlands were more productive (as measured by turtle growth and body condition) than permanent lakes (Roe and Georges 2008). The reverse was true during dry periods. Vernal pools may be local sinks for nutrients. Soil chemistry data taken along the upland-basin gradient in soils formed in the Redding soil series support this conclusion (See Table 3.3) although Weitkamp *et al*. (1996) found the reverse in larger, less connected pools underlain by basalt bedrock.

Wetlands are well known for performing critical biogeochemical functions, such as denitrification (Ponnamperuma 1972, 1984) and DOC production (Fogg 1977). The shallow waters of wetlands favor biogeochemical processes because of the high degree of sediment-water interface (Cronk and Fennessy 2001). Ponnamperuma (1984) discusses how standing water impacts biotic zonation (aerobic and anaerobic interfaces), electrochemical changes (redox potentials, pH, specific conductance[2], ion exchanges and sorption and resorption), and chemical transformations (accumulation of carbon dioxide, reduction of minerals and nitrogen transformations). However, in four vernal pool catenas in California's Central Valley, O'Geen *et al*. (2008) found that redoximorphic features corresponded better with the thickness of the soil above restrictive horizons (when they were duripans) than with the length of ponding duration.

Vegetation Communities

Vernal pools support a distinct flora dominated by endemic species, many of which are exceedingly narrow in their distribution (Bauder and McMillan 1998, Keeley and Zedler 1998, Stebbins 1976, Thorne 1984). Over 200 plant species are restricted to or commonly occur in the vernal pools of California (Holland 1976). Of these, 91% are considered native to California and 55% have ranges entirely within the state (Holland 1976, Holland and Jain 1981). *Pogogyne nudiuscula* (Otay mesa mint) is an extreme example of narrow endemism. It is strongly associated with a particular soil series with an area of <8 mi^2 in southern San Diego County and a small area in adjacent Baja California, MX (Bauder and McMillan 1998).

Pools form on an array of substrates across many degrees of latitude and thousands of feet of elevation (Holland 1978). Therefore, it is not surprising that entire suites of unique species are found in vernal pools with distinct soils and climate (Bauder and McMillan 1998, Holland and Dains 1990, Holland and Jain 1981, Keeler-Wolf, *et al.* 1998, Norwick 1991). A species list developed for coastal San Diego County has 37 native species primarily found in vernal pools and an additional 17 native species that are common in pools but not restricted to them (Bauder 1997 and Appendix D.3). The list would contain additional species if the area of focus were enlarged from the coastal mesas and valleys to include the mountains and inland valleys and mesas and similar areas in adjacent counties (Bauder and McMillan 1998).

The vegetation matrix surrounding pools also changes with elevation, latitude and soil substrate. Pools may be embedded in forests and savannas, grassland, chaparral, coastal sage scrub or even maritime succulent scrub in San Diego County and northern Baja California, MX.

Vernal pools are populated by species with various adaptations for living in an ephemeral and unpredictable environment. Most of the species are annuals so that they spend the drought season as seeds in the soil. If rainfall is sparse during the wet season, they often fail to germinate

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[2] Specific conductance, electrical conductance and electrical conductivity are terms that are functionally synonymous and may be used interchangeably for the purposes of this guidebook. Specific conductance is used preferentially in this document, especially where use of this term can avoid confusion with hydraulic conductivity (permeability).

primarily due to lack of moisture, rather than an innate dormancy (Bauder unpublished data). Temperature also affects germinability, with most species germinating at lower rates or not at all when temperatures are higher than those commonly experienced during the winter rainy season (Bauder unpublished data, Bauder 1992, Bauder *et al.* 2002). This protects vernal pool seeds from germinating after the occasional summer rainstorm or during an unusually warm winter when maturity to reproduction is unlikely.

Geophytes are another important component of the pool vegetation. Plants with bulbs, corms or thickened caudices can store up resources during good years to carry them through ones unfavorable for growth.

Many pool species have physiological or morphological plasticity. A typical inundation response is elongation of the stem internodes. This has been observed in *Downingia concolor* spp. *brevior, Downingia cuspidata*, *Pogogyne abramsii* and *P. nudiuscula*, *Marsilea vestita* and *Callitriche marginata*. *Downingia concolor* ssp. *brevior* plants had an average height of 9.0 cm when grown without inundation, compared to 16.7 cm after 8 weeks of inundation. After 8 weeks of inundation, 4 weeks of exposure was sufficient to allow development of flowers equal in number to those of plants only inundated 2 weeks, but plants never inundated had nearly twice as many flowers as plants inundated for 2 or 8 weeks (Bauder 1992). *Pogogyne abramsii* plants were grown in pots exposed to three moisture conditions: no inundation, 21 days of inundation and 60 days of inundation. After 21 days of inundation, the longest stem on the tallest plant in each submerged pot averaged 14.5 cm. The tallest stems of plants never inundated were on average 8.0 cm. The longest stem in each pot submerged for the full 60 days was on average 16.4 cm tall (Bauder unpublished data). Stems of *Downingia*, *Pogogyne* and *Eryngium* species are hollow (aerenchymatous) when water is standing and become fibrous and often hairy or prickly as the ponds begin to dry. In *Callitriche* species, two leaf forms are produced: terrestrial strap-shaped leaves and paddle-like floating aquatic leaves that develop after water has ponded for several weeks (Deschamp and Cooke 1983, 1984). Physiological plasticity (shifts in photosynthetic pathways) has been observed in vernal pool species of *Isoetes*, *Callitriche*, *Crassula*, *Downingia*, *Eryngium* and *Orcuttia*, among others (Keeley 1999).

Although pool species are adapted for periods of inundation, they are not truly aquatic and mortality rises with length of inundation (Bauder 1987a, 2000). The response to inundation period varies by species. Those commonly found in shallow pools or edges of deeper pools have less inundation tolerance than species associated with deeper pools or elevations within pools where water stands longer (Bauder 2000). The presence of dense stands of perennial sedges like *Eleocharis macrostachya* is an indication of long inundation periods, natural or artificial. Modest changes in the pattern of precipitation during the rainy season or the total amount of seasonal precipitation could potentially have profound impacts on the floral composition of southern Californian vernal pools as well as the dominant species in pool basins (Bauder 2005). Human-caused alterations to pool hydrology also affect pool vegetation, tipping the balance towards species, both native and introduced, that tolerate more or less moisture than is typically found in undisturbed pools.

Until recently, introduced species were generally kept in check by their intolerance of standing water (Bauder 1987a, 2000; Holland and Jain 1988). Most of the introduced species in and around vernal pools are easily dispersed rangeland annuals originating in Asia. During drier years, they germinate and thrive in pool basins. In wetter years, they may germinate when the rainy season begins but experience near complete mortality in pools or portions of pools where water stands continuously for 10 days or more (Bauder 1987a, 2000). Many pool species react adversely to competition—inter- or intra-specific—with reduced biomass or fecundity, increased mortality or both (Bauder 1987a, 1989; Bauder *et al.* 2002). Standing water provides them with an escape from competition with the rangeland annuals. Ponding does not provide relief from the competitive effects of a number of wetlands exotics that have become established in many southern Californian vernal pools (Bauder 1988, Bauder *et al.* 2002). These include *Polypogon monspeliensis* (annual beard grass or rabbitfoot grass), *Lolium* spp. (ryegrass), *Lythrum hyssopifolium* (grass poly) and *Agrostis avenacea* (blown grass or Pacific bent grass).

Faunal Communities

Vernal pools provide habitat that is used by a wide variety of animals throughout their life cycle. Vernal pools that have a high degree of faunal functionality maintain this characteristic set of species that are uniquely adapted to the bi-phasic nature of the resource. In addition to the opportunities for food and reproduction provided by the pool itself (during either the wet or dry phase), connectivity among pools at the landscape level may also be important for some species. This is because 1) their life cycle requires access to both ephemeral pools and other habitat types, or 2) the ecological and evolutionary consequences of dispersal and gene flow among pools in a complex are essential for persistence in individual pools. The second set of processes may be addressed in terms of metapopulation processes, source sink dynamics or maintenance of genetic diversity, depending on the context. Spatial linkages among vernal pools and adjacent habitats within the surrounding landscape facilitate the long-term persistence of a diversity of habitats and characteristic vernal pool plant and animal communities (Ebert and Balko 1987, Hanski 1996, Hansson *et al.* 1995, Holland 1976, Holland and Jain 1981, Simovich, 1998, Thorp and Leong 1998).

Some animals found in vernal pool are "obligates" whose entire life cycle is completed within the pool. The most obvious examples are crustaceans, but this group also includes nematodes, rotifers and other taxa. The life cycle of obligates is precisely tied to the pools, and these species typically persist through the dry phase as dormant propagules in the pool sediment. Dormant propagules (typically encysted eggs or embryos) hatch when the pools fill, and the organisms quickly mature and reproduce before the pool dries. Some are generalists found in pools that span a variety of abiotic conditions. However, most exhibit limited tolerance ranges for water temperature, chemistry (pH, salinity, alkalinity, turbidity, etc.) and pool duration (due to minimum developmental times). As a result, most vernal pool obligates are narrow endemics found only in a limited geographic area. These organisms feed on those lower in the food chain including algae, bacteria, smaller animals and detritus. They are in turn fed upon by amphibian larva and migratory waterfowl (Baker *et al.*1992). Dispersal among pools and pool complexes is often mediated by vectors such as birds and mammals. Thus, gene flow, recolonization and potential rescue of pools with low density are all dependent upon maintenance of appropriate vectors.

Vernal pools in the reference domain contain at least three species of fairy shrimp that are obligates: the San Diego fairy shrimp *Branchinecta sandiegonensis*, Lindahl's fairy shrimp (also known as the versatile fairy shrimp) *B. lindahli* and the Riverside fairy shrimp *Streptocephalus woottoni*. The San Diego fairy shrimp and the Riverside fairy shrimp are federally endangered species, so appropriate USFWS permitting issues must be addressed before sampling pools in which these species may be present.

A second set of organisms are "lifestyle dependent," since they spend only a part of their life cycle in the pools, or are dependent on other pool organisms at a certain stage. The most obvious in this group are the amphibians. While some species such as tree frogs can breed in intermittent streams as well, spadefoot toads are in large part dependent on predator-free ephemeral pools. The adults spend the dry season under the ground or in the uplands, rather than the pools. Spadefoots take advantage of rodent burrows to help them get up to a meter deep in the ground. Although tree frogs may exhibit an extended period of activity in the wet season, spadefoots are more precisely adapted to the pool cycle. After emerging during heavy rains (thought to be cued by the sound) they quickly move to pools and breed in one or a very few nights. The adults then return to shallow burrows in the uplands and emerge at night to feed for a short period of time. Tadpoles develop quickly eating pool vegetation, and even more quickly if fairy shrimp are available as prey. Upon metamorphosis, they too return to the uplands.

A large variety of lifestyle dependent insects also utilize vernal pools, generally for the development of their larval stage. Terrestrial (aerial) insect adults come to the pools to deposit eggs. Many insect larva are predators on other vernal pool animals. Most vernal pool insects with aquatic larvae will also utilize other water sources, and are thus not totally reliant on ephemeral pools. However, some insect pollinators are obligately dependent on vernal pool plants, with which they have co-evolved specific pollination syndromes.

Finally, some vernal pool animals are best characterized as "opportunists" that take advantage of pools when available. Included are some insects and migratory waterfowl (which may have been more dependent on these pools in the past when they were more abundant). These use the pools as resting and feeding stations. Some species breed around pools. Mammals will also use pools for water sources, and garter snakes feed on tadpoles when available.

In general, it is widely recognized that vernal pools support a unique assemblage of fauna due to the timing and duration of inundation phases; these are in turn dictated by climate, soil characteristics, hydrology and the microtopography of the pool basin (*e.g.*, Bauder *et al.* 1998, Hanes and Stromberg 1998, Holland and Jain 1988, Keeley and Zedler 1998, Smith and Verrill 1998, Sutter and Francisco 1998). Although vernal pools are sometimes thought of as isolated "bathtubs" driven solely by precipitation and evaporation, they are often linked hydrologically to the remainder of the landscape by groundwater flow through perched aquifers (Rains *et al.* 2006). As in many other areas, both rainfall patterns and vernal pool inundation patterns are highly variable in southern California (*e.g.*, Bauder 2005). For animals such as crustaceans that live in these temporary habitats, the fraction of cysts that hatch has evolved to match environmental predictability. To persist in a pond that does not always remain full long enough for maturation and mating, < 100% of cysts hatch during any particular hydration. This phenomenon has been very well studied theoretically and empirically (*e.g.*, Brendonck 1996, Philippi *et al.* 2001, Brendonck and De Meester 2003, Brock *et al.* 2003). For example, in the San Diego fairy shrimp, only 6% of *B. sandiegonensis* cysts hatch during laboratory hydrations (Simovich and Hathaway 1997), and the average pool containing *B. sandiegonensis* fills long enough to allow reproduction approximately once in every three inundation events (Philippi *et al.* 2001).

Cultural Alteration of Wetland Basins and the Landscape

Vernal pools were once a common feature in southern California, from the Transverse Ranges in the north, across the Los Angeles Basin to western Riverside County, coastal Orange County and both coastal and inland San Diego County. They used to dominate San Diego's coastal mesas. The losses to development have been extensive, although a firm number or percentage is hard to determine. Examination of old aerial photographs and soils maps is one of the few ways to estimate the original and remaining acreage of suitable landscape for vernal pools (Bauder and McMillan 1998). When the first endemic pool species attained Federal and State Endangered

Status (*Pogogyne abramsii*—FE 1978, SE 1979), two intensive pool mapping efforts were launched in San Diego County (Beauchamp 1979 and Villasenor and Riggan 1979). The pools mapped in 1978/1979 were revisited in 1986 to determine how many had been preserved or lost and how many remained (Bauder 1986). The development of Habitat Conservation Plans in the 1990's spawned yet another intensive mapping effort (City of San Diego 1998). It is generally agreed that over 95% of the original number of pools has been lost, that pools continue to be lost, and that those remaining are, with only a few exceptions, contained within small parcels that are often not adequately preserved, protected and/or managed.

As with other parts of California, the pools in southern California were subject to grazing, often intensive, after the Spanish introduced cattle and sheep in the late 1700's. By the mid-20th century, the aridity of the climate coupled with accelerating development led to a decrease in grazing, and it is at present a minor disturbance. Today, the major habitat alterations are direct losses due to development; reduction, fragmentation and disturbance of surrounding landscapes; changes in catchment areas (augmentation and truncation) and drainage patterns; grading and brushing; fires; and disturbance of basins by vehicles, dumping and various edge effects, including the introduction of exotic plants and animals (Bauder 1987b).

4 Wetland Functions and Assessment Models

Overview

The following sequence of topics is used to present a summary of the data collection and analysis and a description of each of the functions:

Reference Data

a. General

b. Site Characterization

c. Catchment and Basin Characterization

d. Direct Measures of Function

Analytical Techniques and Procedures

Functions

The following functions performed by vernal pool wetlands in southern California were selected for model development:

1. Surface and Sub-surface Water Storage
2. Hydrologic Networks
3. Biogeochemical Processes
4. Maintenance of the Characteristic Plant Community
5. Maintenance of the Characteristic Faunal Community

The following sequence of topics is presented for each function:

a. Definition: defines the function and identifies one or more independent quantitative measures that can be used to validate the functional index.

b. Rationale and process that influence the function: provides the rationale for why a function was selected and discusses onsite and offsite effects that may occur as a result of lost functional capacity.

c. Characteristics and processes that influence the function: describes the natural and anthropogenic characteristics and processes of the wetland and the surrounding landscape that influence the function.

d. Functional Capacity Indices, Direct and Indirect: defines the variables used for both direct and indirect indices, presents the index equations and describes the relative contributions of the variables to the indices.

Reference Data

General

A total of 73 reference sites were evaluated over a period of 6 years during different seasons, beginning in the fall of 2000 and ending in the winter of 2007. Data taken in January 2007 were used to refine field protocols and were not included in model development. The reference sites encompass a number of different pool types (coastal mesa pedogenic, inland valley alluvial, etc.) found in Southern California (See Table 5.2) and conditions that range from relatively undisturbed to disturbance via cultivation, brushing, grazing, ripping, grading or significant vehicle impact. Some sites had been enhanced, restored or created *de novo*.

Site Characterization

Site characterization began with the preparation of sketched base maps and aerial photographs for each WAA (Wetland Assessment Area) or PWAA (Partial Wetland Assessment Area). The objectives in the development of the landscape-scale base map(s) were to (a) determine the aerial extent of the current type and level of disturbance in and around the WAA, and (b) place the wetlands in context, noting important landscape features such as drainage networks, roads, culverts, water control structures and signs of past land use such as fire, tillage, type conversion or grazing. In order to assess landscape-level disturbances, the base maps included a 1 km radius circle centered on each pool that was divided into four pie-shaped wedges. The level of disturbance in each wedge was estimated according to disturbance categories developed for this guidebook (See Appendix D.2.)

Catchment and Basin Characterization

For each pool, a base map was developed that identified the basin's outline, inlets, outlets, connections and catchment area. Pool length, depth and width were measured and recorded. Various surface features (cobbles and cracks) and forms of disturbance (fill and mechanized soil disruption) were assessed. Microtopographic maps were made of 45 individual pools and, where relevant, their topographic relationship to nearby pools.

Direct Measures of Function

Detailed direct measurements of four of the five model functions were taken during the 2000/2001 and 2001/2002 rainy seasons. Data from the 2001/2002 rainfall season were considered unreliable due to the extreme drought conditions and were not used in model development. Direct data were collected on the following functions: surface and sub-surface water storage, hydrologic networks and the characteristic plant and faunal communities. Hydrology was monitored by instrumentation in 7 pools and manually in 38 pools. Data collected included precipitation amount and timing, water depth, electrical conductivity (EC) and pH. Vegetation was sampled by taking complete species surveys of the basin and its periphery (a band extending from the basin edge 20 feet into the uplands). Cover of native and exotic herbs was noted, along with the percent bare ground in the basin and the periphery. The invertebrate fauna were sampled weekly when sufficient water was present to support the community. Invertebrate samples were sorted taxonomically under a dissecting microscope in the laboratory.

The remainder of the pools was sampled less intensively in July 2003 (n=16) (middle of the dry season) and January 2007 (n=12) (an exceptionally dry wet season). Data on the invertebrate community could not be collected in either of these periods due to the lack of water. Accurate vegetation data could be collected in July 2003 because the previous wet season had experienced above average precipitation, and it was still possible to identify plants from dead remains. Vegetation data collected in 2007 were not used, when extremely dry conditions prevented germination of most characteristic plant species.

Analytical Techniques and Procedures

For all but the Hydrologic Networks function and Biogeochemical Processes function, we employed graphical and statistical analyses to examine simultaneously a number of variables with a range of values. We then generated FCI equations reflecting their relative contributions to the function. We accounted for interactions among variables when we found them, searched for thresholds and other nonlinear relationships in the data and ultimately discarded many variables that did not logically and empirically have explanatory power for the function. Details of our approach are provided in Chapter 5 in the section titled “Analytical Techniques and Procedures.”

Southern Californian Vernal Pool Wetland Functions

Function 1. Surface and Sub-surface Water Storage

Definition

The surface and subsurface water storage function is defined as the capacity of the vernal pool wetlands complex to capture and store precipitation falling on the basin and catchment area. Moisture is stored within the depression as free water on the surface and/or in the surface and subsurface soils of the pool, swale(s) connecting pools and adjacent uplands. Water moves into and out of the basin by defined inlets and outlets and/or to and from the soil of the associated swales and adjacent uplands. It is also lost by evaporation, evapotranspiration, leakage through the sub-surface soil strata and spillage when the basin's storage capacity is exceeded, if an outlet is present. In this guidebook, we only assess free water on the surface of the basins.

Moisture retention and storage depend on a basin soil profile containing one or more restrictive layers that retard drainage. Surface soils in the depression generally have a high clay content. Underlying the surface horizons may be a cemented hardpan (or “duripan”), accumulated clays, bedrock or other poorly permeable layer(s). Ponding occurs when the soils become fully saturated above the restrictive horizon. The depth and texture of the surface soils within the basin, coupled with the permeability of the sub-layers, govern the amount of water required to initiate ponding and also affect the subsequent hydroperiod, plant rooting depth and moisture availability after surface water disappears. Initiation of the first seasonal ponding event may involve processes that differ from those which sustain ponding following mid- or late-season saturation of the pool’s watershed.

In addition to water, dissolved solids (salts) move from the pool into the bank and downstream through the outlet. Virtually all vernal pools observe an annual cycle commencing with relatively higher salinities during the initial rains of the season, when ponding mobilizes evaporated salts stored on and in the bed of the pool or released from storage in the bank. A mid-season salinity minimum coincides with rainfall onto the inundated area of the pool and flow from the pool into the adjoining banks. Water flows back into pools from adjacent banks as the water table in the surrounding soils rises. Salts are subsequently concentrated by evaporation during seasonal desiccation. Thus, vernal pools store and regulate salts within a given pool complex or network of vernal pools, and modulate the episodic release of salts at the onset of the wet season. Perhaps not surprisingly, some of the plants and animals that typically occupy pools are salt-sensitive.

As with other bodies of water, vernal pools also store and redistribute heat in their narrow niche between the atmosphere and the soils. The life cycles of biota within the pools are often governed by the onset of threshold temperatures early and late in the season.

Quantitative, direct measures for this function include catchment precipitation, water depth, salinity (or dissolved solids, generally measured as specific conductance[1]), water temperature, water table elevations and seasonal hydrographs.

Rationale for Selecting the Function

Surface and subsurface water storage modulates the movement of water in a climate known for highly seasonal, infrequent and often intense storms that generate rapid runoff. Retention of soil moisture beyond the rainy season extends the growing period. Bio-geo-chemical cycling is facilitated in a region where rates of primary productivity and decomposition are limited by aridity. Water, salt and temperature storage provide the necessary conditions for the unique wetland-dependent vernal pool plant and animal communities to develop. Standing water also excludes many species with limited to no inundation tolerance, dictating the nature of biological interactions within the pool. The role of vernal pools in storing and modulating solutes and temperatures also affects habitats further down in the watershed. Together, pools are wetland patches in a matrix of terrestrial, upland vegetation. Even vertebrate and invertebrate animals that do not require standing water of particular salinities utilize the wetland flora and fauna for food, shelter or some portion of their life cycle.

Characteristics and Processes that Influence the Function

Natural Characteristics and Processes

The primary natural influences on the water storage capacity of depressional southern Californian vernal pool wetlands are geomorphology, soil characteristics and the Mediterranean climate. The geomorphic origins of southern California's vernal pools are diverse, ranging from pedogenic to tectogenic to alluvial processes. The origin of the surface on which the pools have developed determines the soil series of the landscape that in turn affects the soil characteristics both of the upland catchment areas and the depressions themselves. Although the entire region experiences a Mediterranean climate, distance from the coast, elevation and presence of a rain

[1] Specific conductance, electrical conductance and electrical conductivity are terms that are functionally synonymous and may be used interchangeably for the purposes of this guidebook. Specific conductance is used preferentially in this document, especially where use of this term can avoid confusion with hydraulic conductivity (permeability).

shadow influence the amount and timing of precipitation, as well as the seasonal temperature regime.

The topography of the landscape affects the size and nature of the catchment area and the volume, directional flow and rate of water movement. Microtopographic features such as pool volume, the presence of inlets and/or outlets and the pool's relative position in a network or chain of pools are important factors determining each pool's unique water storage capacity and hydroperiod. Soil texture and the depth of the various soil layers affect the infiltration rate, the amount of water that can be stored in the soil and the amount and intensity of rain necessary to initiate ponding.

The timing and amount of water movement through vernal pools also regulate the transport of nutrients, organic carbon, sediments and biological propagules. Southern Californian pools on pedogenic or alluviated surfaces occur in a mosaic of hummocks (mounds), swales and depressions—all of similar scale —that direct the capture of precipitation and the flow of water salts, particulates and propagules. Other pools have developed more or less in isolation, and their physical arrangement and connections are less complex.

Regardless of the soil series of the surrounding landscape, the soil profile of pool basins must contain surface and/or sub-surface layers that retard drainage. Generally there is a clayey layer (or layers) 1-2 ft deep, often underlain by an even less permeable claypan, duripan or bedrock layer. The characteristic of the claypan and the presence or absence of the underlying duripan tend to be remarkably similar within a given soil series, even beyond southern California. For example, vernal pools situated in San Diego's Redding soils share many attributes with Central Valley vernal pools in the same soil type. Although the soil profile within pool depressions is universally different than the profile of adjacent uplands, the depression soils have not been formally named or described as a soil series, simply because they are not sufficiently extensive to meet mappable-unit criteria.

The Mediterranean climate is distinguished by a rainy season during the coolest months of the year, followed by a near absence of precipitation during the hottest months. In common with all arid climates, yearly precipitation is unpredictable in amount and within years storm patterns vary. Rainfall interacts with pool landscape position and basin morphology to affect the hydrology of both individual pools and networks of interconnected pools. The intensity, timing within a season and frequency of precipitation events is important to the number, depth and duration of ponding episodes and controls spillage from one basin to another (Bauder 2005, Knudsen *et al.* 1991, Leibowitz and Vining 2003). Because vernal pool wetlands are intermediate between dry, upland ecosystems and permanent bodies of water, even slight changes in pool hydrology can favor species that are not characteristic of vernal pools, possibly leading to major changes in biological interactions.

Mediterranean climates typically display cycles of wet and dry years. Vernal pool fields are almost unique within these landscapes because wet/dry cycle effects are minimal. This is likely due to the limited soil volume of water storage in the typically thin mantle of soils. However, seeds and cysts of some vernal pool species can persist for years or decades awaiting favorable hydrologic conditions. The limitations on water (and on nutrient and salt) storage also highlight how small the annual water storage buffer can be, and (due to the thinness of the soils) the fragility of the pool complexes in many respects.

Human Induced Influences

Human activities affect the capture, movement and storage of water in depressional vernal pool wetlands. Modifications to the uplands, wetland edge or directly to the wetland itself may greatly affect the receipt and retention of water. If catchment areas are augmented or reduced, the altered hydroperiods of individual pools will impact the biogeochemical cycles, the species composition and the phenology, life cycles and population dynamics of individual species residing in both the basins and adjacent uplands. Conversion to urban uses, blading, roads, damming, drains or culverts alter the capture and movement of water. Plowing, disking, grazing, fire and brushing can accelerate erosion of sediments into pools, reducing their volume and altering the soil profile. Soil infiltration rates may be diminished if vegetative cover is reduced or eliminated, or if the populations of burrowing animals that depend upon pools are changed. Alterations to inlets, outlets or pool connections impact the amount and delivery rate of water and the transport of other substances, as well as the persistence of flow into downstream pools and channels, even if the area of the catchment itself remains unchanged. Ripping, disking, blading and other surface and subsurface soil disturbances may alter a pool's ability to pond water by damaging or rearranging the soil layers responsible for water retention. Changes in the soil profile can also affect infiltration rates and soil storage of water within the soils of the basin and the adjacent uplands. Increased inflow can cause channels to form in the swales connecting pools, fundamentally altering their functions. Human induced changes in pool hydrology cause compositional changes to both the plant and animal communities, affect their seasonal development and population dynamics, interfere with the movement of biological propagules and genetic material and impact the various characteristic biological interactions such as predation, herbivory, competition and pollination.

The Hydrological Definition of a Vernal Pool

Extreme alterations to a vernal pool's hydrology can have a number of consequences. For example, retention and storage may be diminished to the point that the depression is no longer recognizable as a wetland of any type. Alternatively, above-ground water retention may be so augmented that the depression has become a permanent or semi-permanent pond, rather than a vernal pool. Although hydrological function can be viewed in absolute terms (the absolute amount of water storage a depression facilitates), we have instead chosen to define it with reference to the natural characteristics of an undisturbed vernal pool system. Specifically, a particular vernal pool functions at its highest level when it stores water at a level and for a period that is typical for an undisturbed vernal pool with the same landscape position, soil profile and level of connectivity. Thus, increases and decreases in an undisturbed vernal pool's water storage capacity lead to loss of function, and depressions that no longer fit the definition of a vernal pool have no value for this function.

Practically speaking, users of this guidebook should evaluate all depressions in terms of the definition of vernal pools as outlined at the beginning of Chapter 3 and in the "Description of the Regional Wetland Subclass" contained within that chapter. For hydrology, the critical elements of that definition are the pool's primary water source (precipitation), topography (natural depression, with or without inlets and/or outlets), seasonality (water ponds during the annual rainy season) and temporariness (ponds dry out once per annual seasonal cycle).

Functional Capacity Indices: Direct and Indirect

Direct Functional Capacity Index

The Direct FCI can only be calculated if seasonal precipitation exceeds 14 cm (See Appendix D.1).

Model Variables

$V_{TOTPRECIP}$ = Total precipitation (cm) for the rainfall year at Lindbergh Field, San Diego.

$V_{PERCENT\_2MONTHS}$ = percent of total precipitation during the rainfall season that fell during the two months with the highest rainfall amounts. Expressed as a whole number between 0 and 100.

$V_{POOLCONNECT}$ = indicator variable that characterizes surface connection of the pool to other pools. 1= none/isolated, 2= headwaters (outlet only), 3= flow through (inlet and outlet), 4=terminal/collector (inlet only)

$V_{TOTINUND}$ = total number of days during the rainy season the pool was inundated, at the lowest elevation.

$V_{PONDING\_EVENTS}$ = number of times the pool was inundated during the rainy season, at the lowest elevation.

$V_{MAXINUNDEPTH}$ = maximum depth of inundation during the season, in cm.

$V_{SC\_TOTINUND}$, $V_{SC\_PONDING\_EVENTS}$, $V_{SC\_MAXINUNDEPTH}$ are scaled versions of the previous three variables, based on $V_{POOLCONNECT}$ and $V_{TOTPRECIP}$ as follows:

<u>Dry years</u>: $14.0 \le V_{TOTPRECIP} \le 17.5$ cm
OR ($17.5 \le V_{TOTPRECIP} \le 25.0$ cm and $V_{PERCENT\_2MONTHS} < 50$)

$V_{TOTINUND}$			0	1-29	30-50	51+
$V_{SC\_TOTINUND}$			0.5	1	0.5	0.1
$V_{PONDING\_EVENTS}$			0	1-3	4-6	7+
$V_{SC\_PONDING\_EVENTS}$			0.5	1	0.5	0.1
$V_{MAXINUNDEPTH}$			0	0.1-11.0	11.1-40.0	40.1+
$V_{SC\_MAXINUNDEPTH}$			0.5	1	0.5	0.1

<u>Average to Above Average years</u>: $25.1 \le V_{TOTPRECIP} \le 32.0$ cm
OR ($17.5 < V_{TOTPRECIP} < 25.0$ cm and $V_{PERCENT\_2MONTHS} \ge 50$)

$V_{TOTINUND}$		0	1-16	17-54	55-140	141+
$V_{SC\_TOTINUND}$		0.25	0.5	1	0.5	0.1
$V_{PONDING\_EVENTS}$		0		1-4	5-8	9+
$V_{SC\_PONDING\_EVENTS}$		0.25		1	0.5	0.1
$V_{MAXINUNDEPTH}$		0	0.1-1	1.1-24.0	24.1-50.0	50.1+
$V_{SC\_MAXINUNDEPTH}$		0.25	0.5	1	0.5	0.1

Wet years: $32.1 \le V_{TOTPRECIP}$						
$V_{TOTINUND}$	0	1-7	8-27	28-108	109-172	173+
$V_{SC\_TOTINUND}$	0	0.25	0.5	1	0.5	0.1

$V_{PONDING\_EVENTS}$	0		1	2-7	8-10	11+
$V_{SC\_PONDING\_EVENTS}$	0		0.5	1	0.5	0.1

$V_{MAXINUNDEPTH}$	0	0.1-4.0	4.1-11.9	12.0-31.0	31.1-50.0	50.1+
$V_{SC\_MAXINUNDEPTH}$	0	0.25	0.5	1	0.5	0.1

Index of Function

The Direct FCI depends on landscape position ($V_{POOLCONNECT}$) as follows:

If ($V_{POOLCONNECT} = 1$)

Direct FCI= $(0.62 \times V_{SC\_PONDING\_EVENTS}) + (0.38 \times V_{SC\_MAXINUNDEPTH})$

If ($V_{POOLCONNECT} = 2$)

Direct FCI= $(0.31 \times V_{SC\_TOTINUND}) + (0.64 \times V_{SC\_PONDING\_EVENTS}) + (0.05 \times V_{SC\_MAXINUNDEPTH})$

If ($V_{POOLCONNECT} = 3$)

Direct FCI= $(0.15 \times V_{SC\_TOTINUND}) + (0.20 \times V_{SC\_PONDING\_EVENTS}) + (0.65 \times V_{SC\_MAXINUNDEPTH})$

If ($V_{POOLCONNECT} = 4$)

Direct FCI= $(0.40 \times V_{SC\_PONDING\_EVENTS}) + (0.60 \times V_{SC\_MAXINUNDEPTH})$

The degree to which a basin provides water storage is a complex function of its depth, length of ponding, and the number of ponding events, calibrated to its particular landscape position (*e.g.*, headwaters vs. terminal pool), and patterns of rainfall in any particular year. Each of the three primary variables for this function ($V_{TOTINUND}$, $V_{PONDING\_EVENTS}$ and $V_{MAXINUNDEPTH}$) is scaled based on precipitation patterns, with a greater amount of water retention expected in years with more rainfall. As seen in the table above, maximum values of 1.0 are obtained for intermediate levels of $V_{SC\_TOTINUND}$, $V_{SC\_PONDING\_EVENTS}$ and $V_{SC\_MAXINUNDEPTH}$ that are characteristic of reference standards. Greater amounts of rainfall facilitate greater discrimination of pool function. For example, each of the three primary variables is scaled based on only 3 bins for low rainfall years, and 5-6 bins for high rainfall years.

The three primary variables correlate to differing degrees with the direct FCI, depending on their landscape position. The total length of inundation does not predict function in isolated pools and terminal pools ($V_{POOLCONNECT}$ = 1, 4), but it is an important variable for headwater and flow through pools ($V_{POOLCONNECT}$ = 2, 3). Similarly, the number of ponding events is the most important variable for isolated and headwater pools, but the maximum inundation depth is more relevant for flow through and terminal pools.

Indirect Functional Capacity Index

Model Variables

$V_{COBBLESBA}$ = 100 X (percent of the basin covered with rounded or angular coarse pebbles or cobbles). Pebbles are 2-7.5 cm in diameter and cobbles are 7.5-25 cm in diameter (Soil Survey Manual, USDA 1993).

$V_{COBBLESBA>15}$ = indicator variable: 0 if $V_{COBBLESBA} \leq 15$,
1 if $V_{COBBLESBA} > 15$.

$V_{MAXDEPTH}$ = maximum depth of the pool in meters, as estimated with surveying equipment.

$V_{MAXDEPTH\_GR}$ = categorical groups for maximum depth of the pool:

$V_{MAXDEPTH\_GR} = 0.32$ if $V_{MAXDEPTH} \leq 0.11$ m

$V_{MAXDEPTH\_GR} = 0.37$ if 0.11 m $< V_{MAXDEPTH} \leq 0.35$ m

$V_{MAXDEPTH\_GR} = 0.00$ if 0.35 m $< V_{MAXDEPTH}$

$V_{DIST1km<5}$ = indicator variable for whether disturbance in the four 1km quadrants is less than Category 5 in all cases: 0 if Dist1km-1 > 4, Dist1km-2 > 4, Dist1km-3 > 4 and/or Dist1km-4 > 4; 1 if Dist1km-1 < 5, Dist1km-2 < 5, Dist1km-3 < 5 and Dist1km-4 all less than 5. (See Chapter 5 “Assessment of Disturbance Levels” and Appendix D.2 for disturbance categories.

$V_{POOLCONNECT}$ = indicator variable that characterizes surface connection of the pool to other pools. 1= none/isolated, 2= headwaters (outlet only), 3= flow through (inlet and outlet), 4=terminal/ collector (inlet only).

$V_{DEFIN\_OR\_OUTLET}$ = 1 if pool has a defined inlet or defined outlet, 0 otherwise.

V_{LENGTH} = length of longest axis (a) in meters, using the basin edge as determined in the field.

V_{SLOPE} = Long axis slope= $V_{MAXDEPTH}$ / (V_{LENGTH} / 2).

V_{SLOPE_GR} = categorical groups for slope:

V_{SLOPE_GR} = 1 if $V_{SLOPE} \leq 1.9$

V_{SLOPE_GR} = 2 if $1.9 < V_{SLOPE} \leq 3.0$

V_{SLOPE_GR} = 3 if $V_{SLOPE} > 3.0$

$V_{IN\_OR\_OUTLET\_WS}$ and V_{SLOPE_WS} = variables specific to the water storage function that are calculated based on $V_{POOLCONNECT}$ as follows:

$V_{POOLCONNECT}$ = 1			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.05	1	0.15
1	0.00	2	0.15
		3	0.00

$V_{POOLCONNECT}$ = 2			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.05	1	0.06
1	0.00	2	0.15
		3	0.00

$V_{POOLCONNECT}$ = 3			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.08	1	0.08
1	0.00	2	0.12
		3	0.00

$V_{POOLCONNECT}$ = 4			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.00	1	0.02
1	0.05	2	0.15
		3	0.00

Index of Function

Indirect FCI = (0.08 x $V_{COBBLESBA>15}$) + (0.35 x $V_{DIST1km<5}$) + $V_{MAXDEPTH\_GR}$ + $V_{IN\_OR\_OUTLET\_WS}$ + V_{SLOPE_WS}

The Indirect FCI indicates that vernal pools with the highest capacity for water storage tend to have cobbles, lie in undisturbed landscapes, and are between 0.11 and 0.35 m deep. In all pools except terminal pools, the presence of a defined inlet or outlet correlates with some loss of function. Moderate slopes between 1.9 and 3.0 are founded in pools with the highest level of function, with more shallow pools tending to retain some level of function.

Function 2. Hydrologic Networks

Definition

Hydrologic networks are the water bodies through which water moves to the local master stream in a vernal pool landscape. The links include pools, the swales or subsurface flowpaths that connect them or the drainages of various types through which flows move into the master stream. Integrated surface/sub-surface water systems are the general rule in California vernal pools (*cf.*, Rains *et al.* 2006, Rains *et al.* 2008) and prairie potholes (Leibowitz and Vining 2003), although subsurface connections between small, surface-isolated wetlands are not well detailed (see Winter and LaBaugh 2003). In this guidebook we only evaluated surface connections.

Pools with neither inlets nor outlets are hydrologically isolated and self-contained, unless the depression's substrata leak water to the sub-surface water table or are structured so as to facilitate underground water movement (Knudsen *et al*. 1991, Rains *et al.* 2006, Rains *et al.* 2008, Winter and LaBaugh 2003). Underground flow fields are more complex when isolated depressions are separated by ridges or mounds (Winter and LaBaugh 2003). Pools isolated on the surface export soil, organic carbon, nutrients or biological propagules primarily by wind and animal vectors.

Pools with inlets and/or outlets are part of an interconnected hydrologic system that may be primarily dendritic and linear, or more anastomosing and reticulate (*cf.*, Hickson and Hecht 1991). The topography of the catchment directs water to the basins. The intensity, timing within a season and frequency of precipitation events is important to the number, depth and duration of ponding episodes and controls spillage from one basin to another (Bauder 2005, Knudsen *et al.* 1991, Leibowitz and Vining 2003). Pools may spill and recharge differently under different precipitation patterns, depending on the height and location of potential inlets and outlets and position in the network or pool order (Bauder 2005). Groundwater connections also vary in response to short or long term changes in the weather (Rains *et al.* 2008, Winter and LaBaugh 2003) and the extent to which the summer soil cracks intrinsic to many southern California pools have seasonally annealed or closed in response to the first storms of the year (Hecht *et al.* 1998, Weitkamp *et al.* 1996).

Soil surface texture is important to the rate of moisture infiltration, the storage of water, and the time it takes for ponding to occur, or if it does occur. The presence and morphology of poorly permeable sub-surface layers affects how water moves through the soil—laterally, vertically or both—and to what degree pools are hydrologically interconnected below ground. Within those pools with deep soil cracks, connections typically change over the course of a season.

Direct, quantitative measures of the movement of water include dissolved constituent concentrations observed over time (Figure 3.6; see also Rains *et al.* 2008), hydrographs of pools in the network (Figure 3.5) and observations on surface flows.

Rationale for Selecting the Function

Water moving through an interconnected system of pools will generally move more slowly and have greater opportunity to infiltrate the soil in and adjacent to the pool basins, swales and channels. Some of the infiltrated water may discharge into the pools and swales (or channels) further downstream. Longer travel times for the water facilitates retention of more moisture in the system for longer periods of time, recharging the ground-water table, perched or not. Longer periods of moisture availability extend the growing season, a significant effect in arid ecosystems with limited and unpredictable precipitation (Bauder 1989, Hecht and Napolitano 1993).

Hydrological interconnections are important for the export and import of nutrients, organic carbon and sediments. Important elements of the food chain such as aquatic invertebrates, algae, fungi, bacteria, plant parts and seeds become mobile when water spills between basins. The movement of sexual or asexual propagules provides the potential for the species composition of pools to change in response to variable or systematically changing conditions (*i.e.*, climate change). Hydrologic connections can also mitigate the genetic drift that can occur in small isolated populations or provide founders for populations that have become locally extinct.

Characteristics and Processes that Influence the Function

<u>Natural Characteristics and Processes</u>

Hydrologic interconnections between pools result from the interplay of catchment and pool topography, climate and soils. The topography of the catchment directs the surface movement of water over the landscape. Along with the soil profile, the shape and depth of individual basins determine the volume of surface water that can be stored, hence the amount required for spillage.

Configurations of basin inlets and outlets depend on the location of swales and channels in the landscape, coupled with small differences in elevation along pool margins. The number and area of basins upstream will influence the duration of flows into a networked vernal pool, as well as the duration of ponding. The locations of inlets and outlets may change with the rate and amount of water flowing through the system or with changes in vegetation growth, sediment and debris deposition and related soil development. The catchment area determines the volume of water that enters and moves through pools, with vegetative cover and soil type playing lesser roles.

The regional Mediterranean climate is characterized by scant precipitation concentrated in the coolest months of the year (Bauder 2005). The amount and pattern of rainfall events is unpredictable within rainy seasons and between rainfall years (July 1-June 30). This climatic variability means that connectedness is a function of the rainfall events in a particular rainfall year, and yearly variation is substantial (Bauder 2005).

Human Induced Influences

Changes to the size and topography of the catchment affect the volume of water entering the pools and the rate and direction of flow. Roads act as dams that diminish flow in some areas, and collect and redirect water. Pools deprived of water may lose their hydrologic connection to other pools or be connected more infrequently. They then become artificially isolated and more vulnerable to local extinctions and invasion by plants and animals with different moisture requirements or tolerances. The potential of "rescue" by propagule import from other pools is diminished.

If a culvert or pipe adds water to the system or if grading connects catchments, the increased volume, rate of movement and force of water can cause spillage where there was none, scour channels and basins, alter inlet and outlet elevations, deliver excess sediment and pollutants and flush basins of nutrients and biological propagules such as seeds and cysts. Trenching that breaches the upper several feet (or more) of the claypan or hardpan, although limited in area, can sharply alter flow within the networks, particularly in dry years. Drainage through backfill placed in utility trenches, if not sufficiently baffled, can permanently re-direct inflows to pools or change their hydroperiods. Catchments that have been bladed, brushed or disked will have different infiltration parameters and be more likely to erode. Deep ripping or conversions to hardscape have even more severe impacts on the normal spillage regime of pools and the nature of their hydrological connections. Conversion of any portion of the catchment—or, in some cases, the landscape—to grazing, agriculture, roads or urban uses, alters the amount of water that can be stored and the timing and direction of water moving through the system. Trails (especially equestrian) and vehicle tracks (off-road, motorcycles, trucks, etc.) can act as drains and dewater an area (Bauder 1994).

Functional Capacity Indices: Direct and Indirect

The functional capacity index for hydrologic networks was developed from observations made in three pool networks: two networks (n=4 and n=8 pools) that were bladed and disked or cultivated over 60 years ago, and a nearly undisturbed pool network of 10 pools. All three networks are of pedogenic origin and developed in the Redding soil series. Data collected from these pool networks indicate that the position within a network influences how often a pool will fill and drain (or evaporate). More rainfall is typically required to establish ponding in pools that are higher in the network, while pools that are lower in the network pond earlier and experience more frequent ponding episodes (See Figure 3.5). Therefore, a network of pools represents an array of interacting pool-specific hydrologic regimes in close proximity to each other. Geomorphic and topographic indicators strongly interact with hydrologic variables to dominate pool network functionality. The Direct FCI can only be calculated if seasonal conditions of precipitation amount are met (See Appendix D.1). In this guidebook, the FCIs for Hydrologic Networks are based on surface connections only.

Direct Functional Capacity Index

The Direct FCI can only be calculated if specific conditions of precipitation pattern and amount are met (See Appendix D.1).

Model Variables

$V_{NETPONDING}$ = number of pools in the network that continuously pond ≥ 5 days during the rainy season.

$V_{HEADWWATERPOND}$ = number of headwater pools that simultaneously hold water at their lowest elevation.

$V_{FILLEDMAX}$ = the number of headwater basins that filled to their maximum depth at least once during the rainy season.

$V_{TOTINUND}$ = total number of days during the rainy season a pool was inundated, at the lowest elevation.

The variables are scaled according to Table 4.1.

Table 4.1. Direct Assessment of the Hydrologic Network Function	
Variables*	
$V_{NETPONDING}$= Number of pools in the network that continuously pond water ≥ 5 days during the rainy season.	
$V_{HEADWATERPOND}$=Number of headwater pools that simultaneously hold water at their lowest elevation.	
$V_{FILLEDMAX}$= Number of headwater pools filled to their maximum depth at least once during the rainy season.	
$V_{TOTINUND}$= Total number of days during the rainy season a pool was inundated, at the lowest elevation.	
$V_{NETPONDING}$	
Measurement or condition- $V_{NETPONDING}$	Index
The number of pools in the network continuously ponding ≥5days is ≥ 7.	1
The number of pools in the network continuously ponding ≥5days is 4-6.	0.5
The number of pools in the network continuously ponding ≥5days is 3.	0.4
The number of pools in the network continuously ponding ≥5days is 2.	0.25
Zero or one pool in the network continuously ponds ≥ 5 days.	0
$V_{HEADWATERPOND}$	
Measurement or condition- $V_{HEADWATERPOND}$	Index
Three or more headwater pools pond at the same time.	1
Two headwater pools pond at the same time.	0.75
One headwater pool ponds.	0.5
No headwater pools pond.	0.25
No headwater pools pond when >35 cm of rain falls in a 3-month period.	0
$V_{FILLEDMAX}$	
Measurement or condition- $V_{FILLEDMAX}$	Index
Three or more headwater pools fill to their maximum depth.	1
Two headwater pools fill to their maximum depth.	0.75
One headwater pool fills to its maximum depth.	0.4
No headwater pools fill to their maximum depth.	0.25
Only the terminal pool fills to its maximum depth.	0
$V_{TOTINUND}$	
Measurement or condition- $V_{TOTINUND}$	Index
One or more pools in the network pond for a seasonal total of ≥40≤60 days.	1
One or more pools in the network pond for a seasonal total of ≥30≤40 days.	0.75
One or more pools in the network pond for a seasonal total of ≥15≤30 days.	0.4
One or more pools in the network pond for a seasonal total of ≥0≤15 days.	0.25
No pools in the network pond during the rainy season.	0
FCI= $(V_{NETPONDING} + V_{HEADWATERPOND} + 1.5 \times (V_{FILLEDMAX}) + (V_{TOTINUND}/2))/4$	
* Scoring of variables is more fully explained on the data forms in Appendix C.	

Index of Function

Direct FCI= $(V_{NETPONDING} + V_{HEADWATERPOND} + (1.5 \times V_{FILLEDMAX}) + (V_{TOTINUND}/2)) / 4$

The network functional capacity increases as the number of pools in the network holding water 5 days or more increases, the number of headwater pools simultaneously holding water increases, the number of basins reaching their maximum capacity increases (which favors spillage) and with the total number of days water stands at the lowest elevation within the basins.

<u>Indirect Functional Capacity Index</u>

Model Variables

$V_{NUMPOOLS}$ = number of pools in a network of pools as determined by field surveys.

$V_{DOMIDISTBA\text{-}NET}$ = indicator variable for the dominant disturbance within the basins in a network. (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories.)

$V_{DOMDISPERI\text{-}NET}$ = indicator variable for the dominant disturbance in the 20-ft peripheral band surrounding the basins in a network. (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories.)

$V_{DOMDISCA\text{-}NET}$ = indicator variable for the dominant disturbance in the catchment area of the pool network. (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories.)

$V_{MODIFCAT\text{-}NET}$ = indicator variable for the type of modification made to the catchment area of the pool network. (1= none, 2= draining/diminishment/truncation, 3= addition/augmentation)

$V_{SEDFILLBA\text{-}NET}$ = indicator variable for the observable deposition of sediment or fill in most of the basins in the network as indicated by deltaic deposition patterns or soil discontinuities in texture or color (1= none, 2= <25% of basin surface, 3= ≥25% of basin surface).

$V_{INLETELEV\text{-}NET}$ = indicator variable for the discernible modification to the inlet elevations of the basins in the network. (1= none, 2= raised, 3= lowered, 4= trenched/ditched)

$V_{OUTLETELEV\text{-}NET}$ = indicator variable for the discernible modification to the outlet elevations of the basins in the network. (1= none, 2= raised, 3= lowered, 4= trenched/ditched)

The variables are scaled according to Table 4.2.

Table 4.2. Indirect Assessment of the Hydrologic Network Function

Variables*

$V_{NUMPOOLS}$= Number of pools in a network of pools as determined by surveying.

$V_{DOMDISTBA\text{-}NET}$= Dominant disturbance within the basins in a network.

$V_{DOMDISTPERI\text{-}NET}$= Dominant disturbance in the 20-ft peripheral band surrounding the basins in a network.

$V_{DOMDISTCA\text{-}NET}$= Dominant disturbance in the catchment area of the pool network.

$V_{MODIFCAT\text{-}NET}$= Type of modification made to the catchment area of the network.

$V_{SEDFILLBA\text{-}NET}$= Observable deposition of sediment or fill in the basins in the network.

$V_{INLETELEV\text{-}NET}$= Discernible modification to the inlet elevations of pools in the network.

$V_{OUTLETELEV\text{-}NET}$= Discernible modification to the oulet elevations of pools in the network.

$V_{NUMPOOLS}$

Measurement or condition- $V_{NUMPOOLS}$	**Index**
The number of pools in the network is ≥7.	1
The number of pools in the network is 4-6.	0.5
The number of pools in the network is 3.	0.4
The number of pools in the network is 2.	0.25
The pool is isolated.	0

$V_{DOMDISTBA\text{-}NET}$

Measurement or condition- $V_{DOMDISTBA\text{-}NET}$	**Index**
Dominant disturbance in the basins of the network is Category 1 or 2.	1
Dominant disturbance in the basins of the network is Category 3.	0.75
Dominant disturbance in the basins of the network is Category 4.	0.5
Dominant disturbance in the basins of the network is Category 5.	0.25
Dominant disturbance in the basins of the network is Category 6.	0

$V_{DOMDISTPERI\text{-}NET}$ and $V_{DOMDISTCA\text{-}NET}$

Measurement or condition- $V_{DOMDISTPERI\text{-}NET}$ and $V_{DOMDISTCA\text{-}NET}$	**Index**
Use the same scale as the one used for $V_{DOMDISTBA\text{-}NET}$	

$V_{MODIFCAT\text{-}NET}$

Measurement or condition- $V_{MODIFCAT\text{-}NET}$	**Index**
Catchment area for the pool network has no modifications.	1
Catchment area for the pool network has been added to/augmented by < 15%.	0.8
Catchment area for the pool network has been increased by > 35% but < 50%.	0.5
Catchment area for the pool network has been drained or diminished; truncated by < 15%.	0.5
Catchment area for the pool network has been drained or diminished; truncated by > 25%.	0.25
Catchment area has been drained, diminished or augmented by a net > 50%.	0

(continued)

Table 4.2. Indirect Assessment of the Hydrologic Network Function	
$V_{SEDFILLBA\text{-}NET}$	
Measurement or condition- $V_{SEDFILLBA\text{-}NET}$	**Index**
No observable deposition of sediment or fill in most of the basins in the network.	1
Observable deposition of sediment or fill covers <25% of most basins in the network.	0.5
Observable deposition of sediment or fill covers ≥25% of most basins in the network.	0.25
$V_{INLETELEV\text{-}NET}$ and $V_{OUTLETELEV\text{-}NET}$	
Measurement or condition- $V_{INLETELEV\text{-}NET}$ and $V_{OUTLETELEV\text{-}NET}$	**Index**
The inlets/outlets in most of the basins in the network have no discernible modification.	1
The inlets/outlets in most of the basins in the network have been lowered.	0.5
The inlets/outlets in most of the basins in the network have been raised.	0.3
The inlets/outlets in most of the basins in the network have been lowered and trenches or ditches connect most pools.	0.2
(concluded)	
FCI= $(V_{NUMPOOLS} + V_{DOMDISTBA\text{-}NET} + V_{DOMDISTPERI\text{-}NET} + (V_{DOMDISTCA\text{-}NET}/2)$ $(V_{MODIFCAT\text{-}NET}/2) + V_{SEDFILLBA\text{-}NET} + V_{INLETELEV\text{-}NET} + V_{OUTLETELEV\text{-}NET})/7$	
* Scoring of variables is more fully explained on the data forms in Appendix C.	

Index of Function

Indirect FCI= $(V_{NUMPOOLS} + V_{DOMDISTBA\text{-}NET} + V_{DOMDISTPERI\text{-}NET} + (V_{DOMDISTCA\text{-}NET}/2) + (V_{MODIFCAT\text{-}NET}/2) + V_{SEDFILLBA\text{-}NET} + V_{INLETELEV\text{-}NET} + V_{OUTLETELEV\text{-}NET}) / 7$

Factors that correlate with hydrologic network function are the number of pools in the network (more connections lead to greater between-basin movement of water, nutrients and propagules) and the extent of disturbance. This includes disturbance in the basin and surrounding area (periphery, catchment), deposition of sediment or fill and alteration of basin inlets or outlets.

Function 3: Maintain Characteristic Biogeochemical Processes

Definition

Like other wetland ecosystems, vernal pools process and cycle elements (*e.g.*, carbon, nitrogen, phosphorus) that are important to sustaining viable populations and communities in the catchment basin and downstream. The cycling of nutrients and other elements in these small systems is driven in part by the import-export of materials through hydrological transport (Bedford 1996, Jocqué *et al*. 2007, Rains *et al.* 2006, Rains *et al.* 2008) and in part by metabolism of organisms, including anabolic (*e.g.*, primary and secondary production) and catabolic processes (*e.g.*, respiration, decomposition) (Boon 2006, Cronk and Fennessy 2001). Wetlands are well known to have biogeochemical processing rates that exceed those in most terrestrial ecosystems (Mitsch and Gosselink 2000, Schlesinger 1997). Due to the arid climate of the San Diego region, this difference is more pronounced, even though vernal pools may be immersed for only part of a year. Undisturbed San Diego vernal pools are oligotrophic ecosystems, because water inputs in undisturbed pools are largely via rainfall or local interflow among pools, rather than overland flow throughout catchment basins, and because pools are located on ancient, well-leached soils and have relatively brief hydroperiods. Anthropogenic eutrophication, alterations to hydrology (*e.g.*, enhanced overland flow via impermeable surfaces or artificial conveyance structures) and soil disturbances in the basin or its catchment (*e.g.*, earth-moving, alteration of inlets and outlets, etc.) can all alter the typically oligotrophic vernal pool biogeochemical functions.

Rationale for selecting the function

Biogeochemical processes represent an integrative measure of the ecological function of an ecosystem, and so represent an overall measure of ecosystem functional integrity, including the effects of anthropogenic eutrophication, soil disturbances, sediment and chemical runoff, and landscape-scale disturbances. As such, biogeochemical cycling and processing provide a tool to evaluate vernal pool function not provided by other HGM functions that focus on biota or physical variables.

Characteristics and Processes that Influence the Function

Hydrology, soil structure and composition and vegetation are key to biogeochemical processes. Hydrology drives the import and export of materials, as well as the oxidative state of the water and underlying sediment, and thus the selective conditions for vegetative and microbial uptake and processing of materials. Soil structure (or conversely, soil disturbance) is critical because deposition and leaching of materials occur in soils. The long-term development of aerobic/anaerobic interfaces also determines nutrient availability and organic matter processing rates. Soil composition affects the supply of particular minerals, the cation exchange capacity and pH. Vegetation responds to both hydrology and soils, and serves as a major processor of nutrients and organic matter production.

An assessment of biogeochemical function requires integrative analyses over extended time periods. Ideally, this would include variables related to phosphorus and nitrogen flux, and organic matter processing. Direct measures of this function would include estimates of primary productivity for algae and flowering plants, documentation of litter decomposition rates and the presence, concentration and form of various elements and compounds tied to specific processes (*e.g.*, denitrification), breakdown of organic compounds and changes in availability of various compounds related to changes in pH and oxidation states. It is clear from the literature that the hydrology, soils and geomorphology of basins and catchments are all strongly related to biogeochemical processes occurring in wetlands. Thus, variables such as seasonal hydrographs, catchment area, network position and basin morphometry might be good candidates for indirect indicators of function.

For this HGM guidebook, we had intended to do chemical and textural analysis of soils collected from the adjacent uplands, basin edge and pool bottom. Due to equipment failure in the analytical laboratory, we were not able to use these data. We had also prepared for chemical analysis of water samples collected three times during one rainy season. Unfortunately, San Diego experienced its driest year on record during that particular rainy season, and no basins held water. Vegetative cover data were unusable, due to the extreme drought.

Function 4. Maintain Characteristic Plant Community

Definition

The plant community function is defined as the capacity of the wetland habitat to support persistent populations of plant species characteristic of vernal pools in southern California. These populations consist of actively growing plants; dormant structures such as roots, stems, caudices, corms, and bulbs; and the soil seed bank. Soil type and depth, pool hydrology and catchment topography interact with climate to provide suitable conditions for the growth and reproduction of this plant community known as vernal pool ephemeral (Thorne 1976).

Direct measures of this function include plant surveys, estimates of native plant cover, recovery or germination of propagules from the soil and the collection of multi-year population data for key species. Indirect measures would include indicators of a suitable soil profile and capacity to pond.

Rationale for Selecting the Function

This function is important for the intrinsic value of the plant community, which is dominated by endemic species, many of which have very limited distributions. It is also important to numerous wetland processes such as productivity and biogeochemical cycling as well as providing food and habitat for animal communities.

Characteristics and Processes that Influence the Function

<u>Natural Characteristics and Processes</u>

The primary natural influences on the capacity of depressional southern Californian vernal pool wetlands to support the characteristic plant community are shared by the "Surface and sub-surface water storage" function. These are geomorphology, soil and the Mediterranean climate. Various combinations of geomorphology, soil series and local climatic conditions result in a multiplicity of unique wetland habitats even within the reference domain (Bauder and McMillan 1998). Elevation and distance from the coast cause deviations from the prevailing regional climate. The pattern of local, unique wetland habitats extends along the western coast of North American from Baja California MX to the State of Washington.

The numerous, unique combinations of environmental conditions have promoted endemism, often very narrow. For example, the genus *Pogogyne* has three species in San Diego County and adjacent Baja California MX. Each species is faithful to a different soil type, and there is no indication their distributions ever overlapped (Bauder and McMillan 1998). Other genera sort out according to elevation. There are two species of *Downingia* in San Diego County. One, *Downingia cuspidata*, occurs near the coast and in the inland valleys. The other species, *Downingia concolor* var. *brevior*, is found in the county's montane wetlands where winter temperatures are lower and yearly precipitation is greater.

Geomorphology is important to the delivery and ponding of water in pool basins, hydrologic connections between pools and the relationship of pools to adjacent uplands. Soils buffer moisture losses and gains by storing and releasing water from pool basins and the surrounding uplands. Plants can use soil water during dry periods between rainstorms and long after standing water has disappeared at the end of the rainy season. Soil moisture and ponding water promote the growth of dense stands of herbaceous plants quite different from the vegetation in the catchment or landscape. These plants provide animals with a broader diet for a longer period of time than does the upland plant community. The species are less woody and likely more palatable and nutritious compared to the xerophytes that dominate the area, although this has never been examined.

Plants that regularly occur in southern California's vernal pool wetlands are well adapted to the bi-phasic nature of the habitat (wet and dry) and the high variability in moisture conditions within and between years. Within rainfall years (July 1-June 30), precipitation varies widely in total amount, storm intensity and the distribution of storms across the wet season (Bauder 2005). To persist in this variable and unpredictable environment, both plants and animals must cope with rising and falling water levels during the rainy season, a large among-year variation in the longest continuous period of inundation, rapid changes from terrestrial to aquatic conditions and back again, and long periods of high air and soil temperatures coupled with lack of moisture. Various traits have been associated with persistence in such stressful or fluctuating environments. These include dormant eggs, cysts or seeds (Baskin and Baskin 1989, Salisbury 1970, Venable and Burquez 1989, Williams 1998), production of drought resistant underground structures such as taproots, corms, caudices or bulbs (Bauder 1992, Crawley 1986ab, Harper 1977, Mueller-Dombois and Ellenberg 1974, Sheikh 1978), morphological plasticity (Crawford 1987; Deschamp and Cooke 1983, 1984; Hook 1984; Horton 1992; van der Sman *et al.* 1991) and physiological plasticity (Keeley and Morton 1982, Keeley *et al.* 1983), precise requirements for breaking of dormancy (Griggs 1976; Leck 1989; Salisbury 1970; Toy and Willingham 1996, 1967; van der Walk & Davis 1978), precocious reproduction, *i.e.* an annual life history (Barrett *et al.* 1993), and tolerance of lengthy periods of inundation (Bauder 1987a, Crawford 1989, Hook 1984, Jackson and Drew 1984).

Long-term studies along transects spanning the full range of elevations (hence moisture conditions) in vernal pool basins indicate that individual species occupy different portions of the soil moisture/inundation gradient in a series of overlapping distribution curves (Bauder 2000). Natural changes in pool hydrology due to climatic changes could favor some species in relation to others through the direct impacts of longer or shorter, more or fewer periods of ponding. Indirectly, competitive interactions can be altered by changes in hydrology (Bauder 1987a, 1989).

Human Induced Influences

Human activities affect vernal pool vegetation in numerous ways. Pool hydrology is changed by increases or decreases in the catchment area. The catchment area can be augmented or decreased by grading and development. Culverts and channels often connect the catchment to a wider area, thus increasing the amount of water delivered to the pools. Another source of augmented water supply is runoff from hard surfaces or irrigation. Artificial conveyance structures concentrate water flow, thus increasing the force of water entering the catchment. Berms, roads, channels, brow ditches or pipes frequently deprive pools of their normal amount of water. Most development results in drainage and runoff management that directs water away from the area to storm drains.

Too much water can favor herbaceous wetland perennials such as *Typha* spp. and *Eleocharis* spp. Exotic wetlands grasses like *Agrostis avenacea* and *Polypogon monspeliensis* thrive in wetter conditions. These species produce a dense thatch that inhibits seedling growth and reproduction of native pool species (Bauder 1988, Bauder *et al.* 2002). If pools have less water, upland species, particularly those introduced from Asia, can become dense in pool basins. In the absence of inundation sufficiently long to kill them (about 10 continuous days), they outcompete the small, vernal pool annuals (Bauder 1987a, 1989). Water arriving with great force scours channels and inlets and delivers sediment and debris into the basins. Most of the native pool species are diminutive, and sediment and debris bury seeds, seedlings and plants. Changes in topography interrupt the normal drainage patterns in the catchment and often separate pools from their associated uplands. Isolated pools are no longer part of the original hydrological network that determined both hydrology and input and output of nutrients and propagules. Loss of the hydrological buffering provided by uplands favors wider fluctuations in basin ponding frequency and depth and soil moisture content which in turn lead to population fluctuations of pool species (Bauder 1987b). Overland transport of seeds or genes via pollen is diminished or eliminated when uplands are brushed, bladed, graded, cultivated, grazed or developed. Herbivory can increase or decrease when the natural predator/prey relationships are interrupted by truncation of the natural upland habitat. Rabbit and rodent populations in the absence of natural predators such as coyotes or raptors would likely increase. Heavy grazing promotes thick sheets of algae that smother plants (Bauder 1994), as does turf management of golf courses, parks and schoolyards.

Reduction of the landscape or catchment area also exposes pools to more disturbances, often termed “edge effects.” Urban “edge effects” include irrigation runoff that frequently contains nitrates, petroleum-based products, herbicides and other chemicals toxic or damaging to vernal pool plants and animals. Domestic pets prey upon native birds and mammals that are part of the native plant and animal community (Soule *et al.* 1992). Landscape plants and irrigation can change the insect fauna by augmenting resources for native or introduced species, especially during the annual drought period. Honeybees, an introduced species, are frequently seen in vernal pools, and it is likely they have impacted the native pollinators such as solitary ground-dwelling bees (J. Mills unpub. data, Schiller *et al.* 1998). Introduced ant species are strongly associated with irrigation and an augmented water supply (Bolger 1997, Suarez *et al.* 1998). Horse, foot, bicycle and vehicle traffic crushes plants, removes soil and creates channels that can dewater an area (Bauder 1994). Dumping of furniture, appliances, construction debris and other forms of trash impacts pools by covering the soil surface and interrupting drainage patterns (Bauder 1986, 1987b; Bauder *et al.* 1998).

Functional Capacity Indices: Direct and Indirect

The direct functional capacity index for maintenance of characteristic plant communities was developed from floral surveys in the basin and adjacent uplands (periphery) of vernal pools in southern California. From these data, both direct and indirect functional capacity indices were created. Because the direct index estimates the function with more precision, it should be used whenever possible, using the protocol described in Chapter 5 and forms in Appendix C. Personnel with taxonomic training specific for southern Californian vernal pools will be required, and the pools will need to be surveyed in at least two separate years with average or above average precipitation (see Table 5.4 and Appendix D.1). The direct index may be estimated in either the wet or dry phase. If the standing water is too deep or if the dry phase follows a year of below average precipitation, the direct index cannot be successfully estimated.

An indirect functional capacity index is also included, although the information it provides is limited. Because function in the plant community can only be assessed accurately through actual examination of the species that are present, the indirect functional capacity index is considered to be only an approximation.

Plant distribution categories are described more fully in Table 5.6 and descriptions of disturbance categories can be found in Table 5.5 and Appendix D.2.

<u>Direct Functional Capacity Index</u>

Model Variables

V_{BA}= total number of plant species in the basin

$V_{BADI\ 1>0}$ = indicator variable for the presence of any species from distribution category 1 in the pool basin. (0 = none, 1 = one or more species present). Category 1 includes 5 vernal pool species that are state or federally listed as endangered, threatened or rare. (See Table 5.6).

$V_{PERIDI\ 12345}$= total number of plant species from distribution categories 1, 2, 3, 4 and 5 that are found in the uplands (20-ft. peripheral band). This includes all species that are not introduced and excludes upland species that are found in the pool basin (Category 6).

$V_{DI\ 2>0}$= indicator variable for the presence of any species from distribution category 2 in the pool basin or uplands. (0 = none, 1 = one or more species present). Category 2 includes 5 basin species and 27 upland species that are narrowly endemic to southern California. If a typical upland species is found in the basin, it is placed in distribution Category 6 rather than Category 2.

$V_{DI\ 67>17}$ = indicator variable for whether there are more than 17 species from distribution Categories 6 and 7 in the pool basin and uplands (0 = 17 or fewer species, 1 = 18 or more species). If a non-introduced species that is typically found in the uplands (20-ft. peripheral band) is instead found in the basin, it is placed in Category 6. Category 7 consists of 66 species known to be introduced to the reference domain.

Index of Function

Direct FCI = (0.02 x V_{BA}) + (0.19 x $V_{BADI\ 1>0}$) + (0.01 x $V_{PERIDI\ 12345}$) + (0.13 x $V_{DI\ 2>0}$) - (0.23 x $V_{DI\ 67>17}$)

The characteristic plant community function is enhanced by the presence of listed species and other natives, especially those with restricted distributions. The function is diminished by the presence of species out of place, *i.e.*, upland plants in the basin, or species introduced into the region. Because upland plants are usually intolerant of inundation, their presence in the basin indicates the absence of standing water in the current season and a less hospitable environment for temporary wetlands endemics.

Indirect Functional Capacity Index

Model Variables

$V_{DIST1km<6}$= indicator variable for whether disturbance in the four 1km quadrants is less than Category 6 in all cases. (0 = Dist1km-1, Dist1km-2, Dist1km-3 and/or Dist1km-4 equal to 6; 1= Dist1km-1, Dist1km-2, Dist1km-3 and Dist1km-4 all less than 6). (See Chapter 5 “Assessment of Disturbance Levels” and Appendix D.2 for disturbance categories).

$V_{DOMDISTPERI\_VEG}$= indicator variable for the dominant disturbance in the 20-ft. peripheral band, recoded for the vegetation function.

(1 = $V_{DOMDISTPERI} < 3$;
0 = $V_{DOMDISTPERI} = 3$;
-1 = $V_{DOMDISTPERI} > 3$).

$V_{DOMDISTBA=1}$= indicator variable for whether the basin is undisturbed per the 6 disturbance categories.

(0 = Domdistba greater than one, 1 = Domdistba equal to one).

$V_{MAXDEPTH<0.36}$= indicator variable for whether $V_{MAXDEP} < 0.36$ m.

(0 = V_{MAXDEP} greater than or equal to 0.36 m,
1 = V_{MAXDEP} less than 0.36 m).

Index of Function

Indirect FCI = 0.2 + (0.2 x $V_{DIST1km <6}$) + (0.2 x $V_{DOMDISTPERI\_VEG}$) + (0.2 x $V_{DOMDISTBA=1}$) + (0.2 x $V_{MAXDEPTH<0.36}$)

The characteristic plant community function is diminished by substantial to severe disturbance in the landscape (within a circle of 1 km radius centered on the pool basin), the basin periphery (20-ft. peripheral band) and the basin itself. Basins that are too deep do not support endemic vernal pool flora because these species have limited tolerance for deep water that stands for long periods of time.

Function 5: Maintain Characteristic Faunal Community

Definition

Ephemeral pools provide habitat for a diverse faunal community adapted to the bi-phasic nature of the resource. The faunal community function refers to the capacity of the vernal pool to provide food, cover, and reproductive opportunities for animal taxa for which these wetlands are essential for some or all parts of their life cycle.

Two estimates of the faunal community function are provided: a direct measure based on crustacean community composition, and an indirect measure based on hydrogeomorphic surrogates. Because no single species or suite of species is a reliable indicator for a functional vernal pool, the direct measure of faunal support is specifically calibrated for a subset of pools found in the HGM reference domain.

The indirect version of the model has been calibrated with crustacean community data from the same subset of pools used for the direct model. Further validation could potentially be provided through expanded faunal surveys that include non-crustacean aquatic invertebrates, aquatic and semiaquatic vertebrates, and terrestrial vertebrates and invertebrates that use vernal pools. Because vernal pool inundation patterns are highly variable depending on the timing and amount of precipitation, additional samples from a greater number of inundation events could also be used to refine model calibration. These data sets can be analyzed with general linear models to derive the best indirect functional capacity index (using HGM variables) based on the direct functional index (based on faunal community summary indices). For each non-Boolean HGM variable, scatterplots or boxplots should be examined for potential threshold effects; as such effects are present in the indirect functional capacity indices described below. Details regarding statistical model development are provided in Chapters 2 and 5 of this HGM guidebook.

Rationale for Selecting the Function

Vernal pools provide habitat that is used by a wide variety of animals throughout their life cycle. Vernal pools that have a high degree of faunal functionality maintain this characteristic set of species. In addition to the opportunities for food and reproduction provided by the pool itself (during either the wet or dry phase), connectivity among pools at the landscape level may also be important for some species. This is because 1) their life cycle requires access to both ephemeral pools and other habitat types, or 2) the ecological and evolutionary consequences of dispersal and gene flow among pools in a complex are essential for persistence in individual pools. The second set of processes may be addressed in terms of metapopulation processes, source sink dynamics or maintenance of genetic diversity, depending on the context. Spatial linkages among vernal pools and adjacent habitats within the surrounding landscape facilitate the long-term persistence of a diversity of habitats and characteristic vernal pool plant and animal communities (Ebert and Balko 1987, Holland 1976, Holland and Jain 1981, Hanski 1996, Hansson *et al.* 1995, Simovich, 1998, Thorp and Leong 1998).

The maintenance of characteristic assemblages of invertebrates and vertebrates are typically included in draft models for depressional wetlands, including vernal pools. However, thus far, there has been little success in developing a rapid assessment technique to directly estimate this function. This is due to the taxonomic complexity and variability of animals within and among vernal pools. Vertebrates and terrestrial invertebrates that utilize vernal pools do not easily lend themselves to functional assessment, due to difficulty in accurate field assessments and/or few previous studies. Consequently, this HGM assesses faunal function for vernal pool crustaceans as a surrogate for the entire fauna. Crustaceans are the most numerically important invertebrate faunal group, and include two federally endangered species.

Broad Faunal Categories

<u>Vernal Pool Obligates</u>: These are organisms whose entire life cycle is completed within the pool. The most obvious examples are crustaceans, but this group also includes, nematodes, rotifers and other taxa. The life cycle of obligates is precisely tied to the pools, and these species typically persist through the dry phase as dormant propagules in the pool sediments. Dormant propagules (typically encysted eggs or embryos) hatch when the pools fill, and the organisms quickly mature and reproduce before the pool dries. Some are generalists found in pools that span a variety of abiotic conditions. However, most exhibit limited tolerance ranges for water temperature, chemistry (pH, salinity, alkalinity, turbidity, etc.) and pool duration (due to minimum developmental times). As a result, most vernal pool obligates are narrow endemics found only in a limited geographic area. These organisms feed on those lower in the food chain including algae, bacteria, smaller animals and detritus. They are in turn fed upon by amphibian larva and migratory waterfowl. Dispersal among pools and pool complexes is often mediated by vectors such as birds and mammals. Thus, gene flow, recolonization and potential rescue of pools with low density are all dependent upon maintenance of appropriate vectors.

Vernal pools in the reference domain contain at least three species of fairy shrimp: the San Diego fairy shrimp *Branchinecta sandiegonensis*, Lindahl's fairy shrimp (also known as the versatile fairy shrimp) *B. lindahli* and the Riverside fairy shrimp *Streptocephalus woottoni*. The San Diego fairy shrimp and the Riverside fairy shrimp are federally endangered species; so appropriate USFWS permitting issues must be addressed before sampling pools in which these species may be present. The distributional patterns of the two *Branchinecta* species have been characterized well enough that their presence figures prominently into the Functional Capacity Index. *B. sandiegonensis* is commonly found in vernal pools with high function. However, within the reference domain for this HGM guidebook, *B. lindahli* tends to occur only in disturbed pools. *S. woottoni* is relatively rare in the HGM reference domain, and was not present in pools that were used to calibrate this function. As a result, this species is not used as a specific indicator of function despite its endangered status. If encountered during sampling, it should be treated like any other crustacean species when calculating $V_{CRUSTSPP}$.

Lifestyle Dependent Organisms: These are organisms that spend only a part of their life cycle in the pools or are dependent on other pool organisms at a certain stage. The most obvious in this group are the amphibians. While some species such as tree frogs can breed in intermittent streams as well, spadefoot toads are in large part dependent on predator-free ephemeral pools. The adults spend the dry season under the ground or in the uplands, rather than the pools. Spadefoots take advantage of rodent burrows to help them get up to a meter deep in the ground. Although tree frogs may exhibit an extended period of activity in the wet season, spadefoots are more precisely adapted to the pool cycle. After emerging during heavy rains (thought to be cued by the sound) they quickly move to pools and breed in one or a very few nights. The adults then return to shallow burrows in the uplands and emerge at night to feed for a short period of time. Tadpoles develop quickly eating pool vegetation, and even more quickly if fairy shrimp are available as prey. Upon metamorphosis, they too return to the uplands.

A large variety of insects also utilize vernal pools, generally for the development of their larval stage. Terrestrial (aerial) insect adults come to the pools to deposit eggs. Many insect larvae are predators on other vernal pool animals. Most vernal pool insects with aquatic larvae will also utilize other water sources, and are thus not totally reliant on ephemeral pools. However, some insect pollinators are obligately dependent on vernal pool plants, with which they have co-evolved specific pollination syndromes.

Opportunists: These are organisms that will take advantage of pools when available. Included are some insects and migratory waterfowl (which may have been more dependent on these pools in the past when they were more abundant). These use the pools as resting and feeding stations (Baker *et al.* 1992). Some species breed around pools. Mammals will also use pools for water sources, and garter snakes feed on tadpoles when available.

Characteristics and Processes that Influence the Function

Natural Characteristics and Processes

In general, it is widely recognized that vernal pools support a unique assemblage of fauna due to the timing and duration of inundation phases; these are in turn dictated by climate, soil characteristics, hydrology and the microtopography of the pool basin (*e.g.*, Bauder *et al.* 1998, Hanes and Stromberg 1998, Keeley and Zedler 1998, Smith and Verrill 1998, Sutter and Francisco 1998). Although vernal pools are sometimes thought of as isolated "bathtubs" driven solely by precipitation and evaporation, they are often linked hydrologically to the remainder of the landscape by groundwater flow through perched aquifers (Rains *et al.* 2006). General descriptions of the origin of southern California's vernal pools, their hydrogeology (water sources and hydrodynamics) soil characteristics and hydrologic variability are found in Chapter 3.

As in many other areas, both rainfall patterns and vernal pool inundation patterns are highly variable in southern California (*e.g.*, Bauder 2005). For animals such as crustaceans that live in these temporary habitats, the fraction of cysts that hatch has evolved to match environmental predictability. To persist in a pond that does not always remain full long enough for maturation and mating, < 100% of cysts hatch during any particular hydration. This phenomenon has been very well studied theoretically and empirically (*e.g.*, Brendonck 1996, Philippi *et al.* 2001, Brendonck and De Meester 2003, Brock *et al.* 2003). For example, in the San Diego fairy shrimp, only 6% of *B. sandiegonensis* cysts hatch during laboratory hydrations (Simovich and Hathaway 1997), and the average pool containing *B. sandiegonensis* fills long enough to allow reproduction approximately once in every three inundation events (Philippi *et al.* 2001).

No single species or taxonomic group is diagnostic for a functional vernal pool. For example, considerable regulatory effort has focused on the San Diego fairy shrimp due to its status as an endangered species, but it is not found in highly functional pools with short inundation times. Thus, an assessment of vernal pool functionality with regards to fauna requires an accurate survey of community composition across the full range of hydroperiods within the geographic and hydrologic domain of the HGM.

Human Induced influences

As described in Chapter 3, human modifications to the uplands, wetland edge or the wetland itself can affect the receipt and retention of water, and thus inundation patterns. Plant and animal communities characteristic of undisturbed vernal pools are generally not present in pools with altered hydrology, and individual species are restricted to pools with particular inundation periods (*e.g.*, Helm 1998, Platenkamp 1998, Simovich 1998, Bauder 2000). For example, disturbed pools tend to facilitate populations of mosquitoes, which are rare or absent in undisturbed pools (*e.g.*, Rogers 1998). In general, many vernal pool crustaceans that are characterized as obligates seem to be more tolerant of human-influenced hydrologic changes than obligate vernal pool plants.

Functional Capacity Indices: Direct and Indirect

The functional capacity index for faunal support focuses on the crustacean community as a surrogate for all vernal pool fauna. We present both a direct and an indirect functional capacity index. The direct index must be based on samples from the wet season, using protocol described in Chapter 5 and Appendix B, and taxonomic identification by personnel with freshwater crustacean training. Such training, for example, would exceed that required for identifying fairy shrimp, as fairy shrimp constitute only one component of the crustacean fauna in a vernal pool.

An indirect functional capacity index is also included, although the information it provides is limited. Thus, the indirect functional capacity index should be considered to be only an approximation. Faunal function can only be assessed accurately through actual collection and analysis of the species that are present. However, if function needs to be assessed when the pool is not holding water, only indirect assessment is possible.

Direct Functional Capacity Index

Model Variables

$V_{MAXDEPTH}$ = maximum depth of the pool in meters, as estimated with surveying equipment.

$V_{CRUSTSPP}$ = total number of crustacean species present.

$V_{FAUNIND}$ = proportion of all crustacean species present that are found in the following list of 14, which are termed "Faunal Indicators":

Cladocera (water fleas): *Alona cf diaphana*, *Ceriodaphnia dubia*, *Macrothrix hirsuticornis*, *Moina micrura*, *Scapholeberis ramneri*, *Simocephalus* sp.

Copepoda (copepods): *Hesperodiaptomus franciscanus*

Ostracoda (ostracods, seed shrimp): *Cypridopsis*, *Cypris pubera*, *Eucypris virens*, *Eucypris* sp., *Herpetocypris*, *Limnocythere*, *Strandesia* sp.

V_{SDFS} = indicator variable for the San Diego fairy shrimp *Branchinecta sandiegonensis*: 0 if absent, 1 if present.

V_{LFS} = indicator variable for the fairy shrimp *Branchinecta lindahli*: 0 if absent, 1 if present.

Dependence on $V_{MAXDEPTH}$

The faunal index can only be estimated directly if $V_{MAXDEPTH} \geq 0.07$ m. There is currently no data set that can be used to describe the characteristic fauna of very shallow pools. Moderately shallow pools, defined as ($0.07 \text{ m} \leq V_{MAXDEPTH} < 0.15$ m), support fewer crustacean species than deep pools, defined as ($V_{MAXDEPTH} \geq 0.15$ m). This is accounted for in the first row of the functional capacity index below.

Index of Function

The direct faunal index is inferred by evaluating against the most restrictive conditions (where the index = 1.0)(See the following table). If these conditions are not met, move down through successive rows until all index conditions in the row are met.

Generic functional definition	Index conditions	Index
Pool is functioning at its optimum level and will do so for the foreseeable future.	{ ($V_{CRUSTSPP} > 10$) and ($V_{FAUNIND} \geq 0.6$) and ($V_{SDFS} = 1$) and ($V_{LFS} = 0$) } <u>or</u> { ($V_{MAXDEPTH} < 0.15$) and ($V_{SDFS} = 1$) and ($V_{LFS} = 0$) }	1.0
Pool is functioning at its highest level but is declining, or is functioning at near-optimal levels and will do so for the foreseeable future.	($V_{FAUNIND} \geq 0.5$) and ($V_{SDFS} = 1$) and ($V_{LFS} = 0$)	0.75
Pool has high functionality, is declining, but is recoverable. Alternatively, the pool retains some functionality, is stable or improving, and is recoverable with moderate external effort.	[{ ($V_{FAUNIND} \geq 0.5$) or ($V_{SDFS} = 1$) } and ($V_{LFS} = 0$)]	0.65
Pool retains some function, but is declining and not recoverable. Alternatively, pool has low function but has the potential for self-recovery or restoration.	($V_{FAUNIND} > 0.0$)	0.25
Pool has low function and probably incapable of recovery.	($V_{CRUSTSPP} > 0$)	0.1
Pool retains no functionality.	($V_{CRUSTSPP} = 0$)	0.0

<u>**Indirect Functional Capacity Index**</u>

Model Variables

$V_{INLETMOD}$ = Indicator variable for discernible modification to inlet: 0= no, 1= raised, 2=lowered.

$V_{MOUNDPRES}$ = Indicator variable for mounds present: 0= no, 1= yes.

$V_{SURFCRACKS}$ = Indicator variable for surface cracks 0= no, 1= shallow, 2= deep (deep=>1 cm wide & 1 dm deep).

Log ($V_{CATCHAREA}$)= logarithm, base 10, of the catchment area (est.) in acres.

Log ($V_{MAXDEPTH}$)= logarithm, base 10, of maximum depth of the pool in meters, as estimated with surveying equipment.

$V_{COBBLESBA}$ = 100 X (percent of basin covered with rounded or angular coarse pebbles or cobbles). Pebbles are 2-7.5 cm in diameter and cobbles are 7.5-25 cm in diameter (Soil Survey Manual, USDA 1993).

Dependence on $\mathbf{V_{MAXDEPTH}}$

The faunal index can only be estimated indirectly if $V_{MAXDEPTH} \geq 0.07$ m. There is currently no data set that can be used to calibrate an indirect function for the characteristic fauna of very shallow pools. Moderately shallow pools, defined as ($0.07 \text{ m} \leq V_{MAXDEPTH} < 0.15$ m), differ from deep pools, defined as ($V_{MAXDEPTH} \geq 0.15$ m), in terms of crustacean communities and hydrogeomorphic variables. Accordingly, separate indirect functional capacity indices are presented for moderately shallow and deep pools.

Index of Function for Moderately Shallow Pools

If ($0.07 \text{ m} \leq V_{MAXDEPTH} < 0.15$ m), the indirect faunal index is calculated as:

$$\text{Indirect FCI} = 0.40 + (0.50 \times (V_{INLETMOD} = 0)) + (0.33 \times \text{Log}(V_{CATCHAREA})) + (0.20 \times (V_{COBBLESBA} > 10))$$

Note that ($V_{COBBLESBA} > 10$) is a Boolean expression, receiving a value of 1 for ($V_{COBBLESBA} > 10$) and a value of 0 otherwise.

If ($V_{MAXDEPTH} \geq 0.15$ m), the indirect faunal index is calculated as:

$$\text{Indirect FCI} = 0.40 + (0.3 \times (V_{INLETMOD} = 0)) + (0.20 \times V_{MOUNDPRES}) + (0.20 \times (V_{SURFCRACKS} > 1)) + (0.15 \times \text{Log}(V_{CATCHAREA})) + (0.75 \times \text{Log}(V_{MAXDEPTH}))$$

Note that ($V_{INLETMOD} = 0$) and ($V_{SURFCRACKS} > 1$) are both Boolean expressions, receiving a value of 1 if the expression is true, and a value of 0 otherwise.

The Indirect FCI reflects the fact that vernal pools with a characteristic crustacean community tend to have large catchment areas in landscapes where mounds are present. Modifications to the pool inlet disrupt hydrologic cycles, negatively impacting crustaceans. Within the basin, features such as cobbles (in shallow pools) and surface cracks (in deeper pools) are also indicative of low disturbance and characteristic hydrologic cycles. For basins deeper than 0.15 m, increases in maximum depth do correlate to some extent with higher crustacean community function.

5 Assessment Protocols

Overview

Previous chapters of this guidebook provided (a) background information on the HGM Approach, (b) wetland variables that are indicators of the level of function, (c) the assessment models consisting of those indicator variables, and (d) use of those indicators and models to describe level of function. This chapter provides the specific protocols that should be followed to conduct a functional assessment of vernal pool depressional wetlands in southern California. These protocols were designed for, and will generally be used within, the context of the permit review process under Section 404 of the Clean Water Act. They may also be used for any other wetland management goals or objectives (*e.g.*, restoration, monitoring) that require independent measures of function for vernal pool wetlands in southern California.

The typical application of this guidebook involves the examination of preproject conditions and forecasting of one or more postproject scenarios. To evaluate likely project impacts, the functional capacity of a wetland is assessed under preproject conditions and compared with the functional capacity under proposed postproject conditions. Data for the preproject assessment are frequently collected under existing conditions. Although data for the postproject assessment are normally based on predictions, an actual postproject assessment may occur. A skeptical, conservative, and well-documented approach is required in defining postproject conditions.[1] This recommendation is based on the often-observed lack of similarity between **predicted** or “engineered" postproject conditions and **actual** postproject conditions.

This chapter is organized into the three main steps necessary to conduct an HGM functional assessment using this guidebook:

Preliminary tasks and assembly of preexisting data

a. Define the purpose and objectives of the assessment.

b. Characterize and collate preexisting data.

[1] Although HGM guidebooks are designed, in part, for use in rapid assessments by junior field scientists, experience has shown that adequate understanding of likely postproject conditions requires significant experience with vernal pool functions and their variations in a range of seasons and years. The prevalence of listed species within the pools compounds the urgency for seasoned interpretation of 1) both pre- and post-project functions and conditions, 2) any ongoing reduction in the number of viable pools, and 3) the difficulty in repairing vernal pools if the unique substratum supporting them is disrupted. This third point makes vernal pools nearly unique amongst the wetland types of the U.S., especially since the substrate may have taken hundreds of thousands or millions of years to develop.

c. Screen for red flags.

d. Define the Wetland Assessment Area (WAA).

e. Determine the Subclass and Type.

f. Describe the precipitation regime.

b. Collection and recording of data

a. Construct base maps.

b. Collect hydrologic, soil and geomorphic data.

c. Collect floral and faunal data.

c. Data entry and analysis

a. Enter and analyze data.

b. Apply the results of the assessment.

Preliminary Tasks and Assembly of Preexisting Data

Statement of Purpose and Objectives

Begin the assessment process by unambiguously stating the purpose and objectives of the assessment. This statement will often be as simple as "The purpose of conducting this assessment is to rigorously project how the proposed project will impact wetland functions." Other potential objectives could be to (a) compare several wetlands as part of alternatives analysis, (b) minimize project impacts, (c) document baseline conditions at the wetland site, (d) establish mitigation requirements, (e) evaluate mitigation success, or (f) evaluate the effects of a wetland management program. A clear statement of the objectives will facilitate communication among the people conducting the assessment and will help to establish the approach taken in conducting the assessment. Of course, the specific approach will probably be different depending on whether the project is a Section 404 permit review, an Advanced Identification (ADID), Special Area Management Plan (SAMP), field work as part of a General Plan or HCP monitoring program, or for some other purpose. For this and other preliminary tasks, complete the Wetland Assessment Area Data Form (Appendix C.1).

Collate Preexisting Data

Site characterization involves describing the project area in terms of climate, landform and geomorphic setting, hydrology, vegetation, soils, land use, groundwater features, surficial geology, urban areas, potential impacts, and any other relevant factors. The characterization should be written and accompanied by base maps and figures that show the project boundaries, local scale topography, jurisdictional wetlands, WAA, proposed impacts, and other important features. Other maps and/or aerial photographs (*e.g.*, NWI, Soil Survey) should be reviewed to obtain information on jurisdictional wetlands within the project boundaries, soil types, plant communities, and adjacent location(s) of impacts. The following source materials and information are typically needed to provide an effective precharacterization of a vernal pool wetland site to complete an assessment efficiently. This list does not preclude use of other materials or information sources but rather describes the minimum needed to characterize a site and complete the assessment:

Topographic maps covering the wetland and the surrounding landscape

- USGS Quadrangle 1:24,000 maps
- 1:2400 topographic or orthophoto topographic maps (County of San Diego)

National Wetlands Inventory maps (1:24,000 and 1:100,000 scale) covering the wetland and the surrounding landscape.

- historical and current aerial photographs
- National Aerial Photography Program (NAPP)
- National High Altitude Photography (NHAP)
- digital orthophotographs covering the wetland and the surrounding landscape
- historic aerial photographs (1928 in San Diego County)

Climatic records (County of San Diego; NWS forecast offices-NOAA)

Soil survey maps (USDA).

Land use history validated through

- historical aerial photographs
- archival maps and data

Surveys and reports

- biological surveys
- environmental documents (EIS, EIR, ACOE permit applications, etc.)
- geotechnical or hydrological reports
- mitigation project proposals and/or reports
- research papers
- prior restoration or creation project reports
- proposed projects (current or prior)

For areas in southern California beyond San Diego County, related information can be obtained from the flood control district or community development agency of the pertinent county.

Following the site characterization steps, immediately check for Red Flag conditions or features that may be inherent to the reference domain.

Screen for Red Flags

Red flags are features within, or in the vicinity of, the project area that merit special recognition or protection based on objective criteria (Table 5.1). Many red flag features, such as those based on national criteria or programs, are similar from region to region. Other red flag features are based on regional or local criteria. Screening for red flag features represents a proactive attempt to determine if the wetlands or other natural resources in and around the project area require special consideration or attention that may preempt or postpone an assessment of wetland function. The assessment of wetland functions may not be necessary if the project is unlikely to occur as a result of a red flag feature. For example, if a proposed project has the potential to impact a threatened or endangered species or habitat, an assessment of wetland functions may be unnecessary since the project may be denied or modified strictly on the impacts to threatened or endangered species or habitat. Detailed discussion of red flag features is outside the scope of this guidebook. The purpose and scope of the assessment would determine which of the red flags would require consideration.

Define the Wetland Assessment Area (WAA)

The WAA is an area of wetland within a project area that belongs to a single regional wetland subclass and geomorphic pool type, and is relatively homogeneous with respect to the site-specific criteria used to assess wetland functions (*i.e.*, hydrologic regime, vegetation structure, topography, soils, successional stage, land use, etc.). In most project areas, there will be just one WAA representing a single regional wetland subclass as illustrated in Figure 5.1. However, as the size and heterogeneity of the project area increase, it may be necessary to define and assess multiple WAAs within a project area. If a WAA encompasses distinctly different wetland subclasses, regardless of whether they are a result of natural variability or anthropogenic alteration, then multiple WAAs should be designated and assessed separately.

At least three situations necessitate defining and assessing multiple WAAs within a project area. The first situation exists when widely separated wetland patches of the same regional subclass occur in the project area (Figure 5.2). The second situation exists when more than one regional wetland subclass occurs within a project area (Figure 5.3). The third situation exists when a physically contiguous wetland area of the same regional subclass exhibits spatial heterogeneity with respect to hydrology, vegetation, soils, disturbance history, or other factors that translate into a significantly different value for one or more of the site-specific variable measures. These differences may be a result of natural variability, differences in pool type or cultural alteration (*e.g.*, farming, urban development, hydrologic alterations) (Figure 5.4). Designate each of these areas as a separate WAA and conduct a separate assessment on each area.

Table 5.1. Red Flag Features and Respective Program, Agency Authority

Red Flag Features	Authority[1]
Native Lands and areas protected under American Indian Religious Freedom Act	A
Hazardous waste sites identified under CERCLA or RCRA	I
Areas protected by a Coastal Zone Management Plan	E
Areas providing Critical Habitat for Species of Special Concern	B, C, I, L
Areas covered under the Farmland Protection Act	K
Floodplains, floodways, or flood prone areas	J
Areas with structures/artifacts of historic or archeological significance	G
Areas protected under the Land and Water Conservation Fund Act	K
Areas protected by the Marine Protection Research and Sanctuaries Act	B, D
National wildlife refuges and special management areas	C
Areas identified in the North American Waterfowl Management Plan	C, L
Areas identified as significant under the Ramsar Treaty	H
Areas supporting rare or unique plant communities	C, H, L
Areas designated as Sole Source Groundwater Aquifers	I, M
Areas protected by the Safe Drinking Water Act	I, M
City, County, State, and National Parks	D, F, L, M
Areas supporting threatened or endangered species	B, C, H, I, L
Areas with unique geological features	
Areas protected by the Wild and Scenic Rivers Act	
Areas Protected by the Wilderness Act	

[1] Program Authority/Agency
A = Bureau of Indian Affairs
B = National Marine Fisheries Service (NMFS) or National Oceanic and Atmospheric Admin.
C = U.S. Fish and Wildlife Service
D = National Park Service (NPS)
E = California Coastal Commission and Bay Conservation & Development Commission
F = California Department of Parks and Recreation
G = State Historic Preservation Officer (SHPO)
H = California Natural Heritage Program
I = U.S. Environmental Protection Agency
J = Federal Emergency Management Administration
K = Natural Resources Conservation Service
L = California Department of Fish and Game
M = Local government agencies

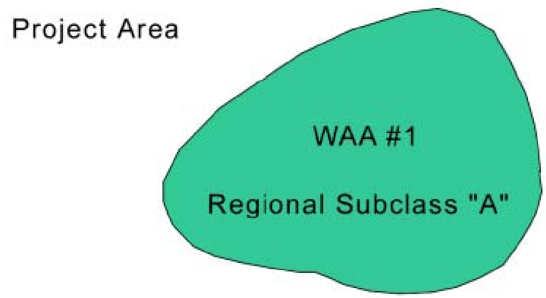


Figure 5.1. A single WAA within a project area.

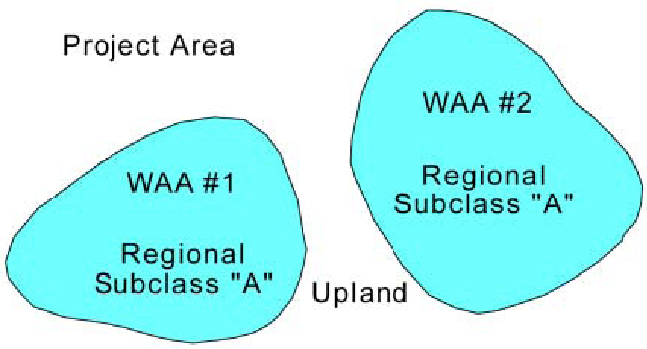


Figure 5.2. Spatially separated WAAs from the same regional wetland subclass within a project area.

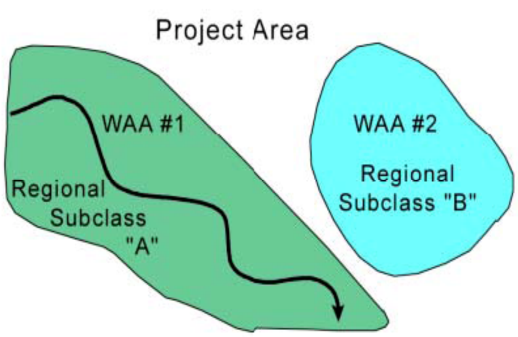


Figure 5.3. More than one regional wetland subclass within a project area.

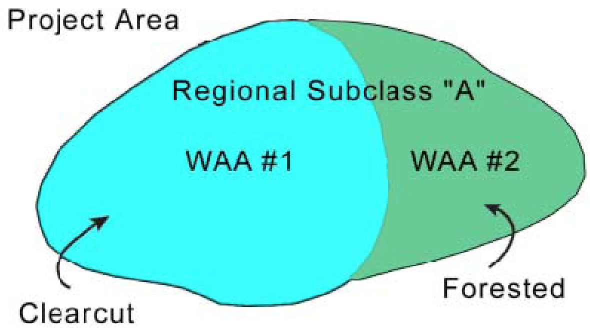


Figure 5.4. WAA defined based on differences in site-specific characteristics.

There are elements of subjectivity and practicality in designating what constitutes a "significant" difference in portions of the WAA. Field experience with the regional wetland subclass under consideration should provide a sense of the range of variability that typically occurs and the “common sense" necessary to make reasonable decisions about defining multiple WAAs. Splitting an area into many WAAs in a project area based on relatively minor differences may lead to an impractical increase in sampling and analysis requirements. In general, differences resulting from natural variability within vernal pool types (Table 5.2) should not be used as a basis for dividing a continuous wetland area into multiple WAAs. However, zonation caused by different hydrologic regimes or disturbances caused by rare and destructive natural events should be used as a basis for defining WAAs, as should different geographies and age/origins (*i.e.* differences in pool types).

Determine the Wetland Subclass and Pool Type

The first task is to determine whether or not the wetland(s) to be assessed occur in topographic depressions on a soil surface with slope < 5 %. Determination of the subclass can generally be completed prior to the site visit using topographic maps of appropriate scale. Vernal pool wetlands in southern California may be <10 cm deep, indicating topographic or orthophotographic maps of 1:2400 scale with contours no greater than 2 ft should be used. The geomorphic origins of vernal pools vary considerably, affecting the soil series, landscape position, hydrology and vegetation of the WAA. It is important to assess the wetlands in the context of their geomorphic origin. Table 5.2 presents a 4 x 6 matrix of different geographies and age/origins, with a potential for 24 different pool types. We have identified locations for 16 types. To assign the type(s) within the WAA, refer to the type descriptions in Table 5.3 and the following section, “Major Vernal Pool Classes of Origin.”

Table 5.2. Matrix of Vernal Pool types in Southern California

Age & Origin	**Geography**			
	Coastal Mesa	Inland Valley	Inland Mesa	Large Depression
Pedogenic	Miramar* Otay Mesa Wire Mesa (Pendleton) Isla Vista#	upper Ramona (Santa Maria Crk) San Marcos small pools at Skunk Hollow	Valle de las Palmas (Baja MX) Wire Mt./Oscar One (Pendleton) Sunrise Hwy	Cuyamaca Little Lagunas
Tectogenic	X	Skunk Hollow (Riverside Co.)	Moorpark (Ventura Co.)	X?
Landslide	Otay Mesa Chiquita/San Clemente (Orange Co.)	X	X	X
Alluviated	Otay Valley Proctor Valley	lower Ramona (Santa Maria Crk) Marron Valley San Marcos Fairview Park (Orange Co.) Hemet	X	Cuyamaca?
Dune dammed	Carlsbad Carmel Mt. (Del Mar) Ellwood Beach# West Bluff (Pendleton)	X	X	X
Bedrock	Colonet (Baja MX)	Tenajas (Riverside Co.)	Santa Rosa Plateau (Riverside Co.)	North LA Co.

*Shaded cells were sampled for reference data. X= no example identified.
Blend of two pool types: Ellwood Beach and Isla Vista pools are a full continuum between dune-dammed (see Napolitano and Hecht 1991) and pedogenic (Ferren and Prichett 1988).

Table 5.3. Description of Age and Origin of Vernal Pool Types in Southern California	
Age & Origin	**Description**
Pedogenic	Vernal pools formed on old or very old terraces or deeply weathered crystalline bedrock by pedogenic processes are the most numerous and widespread. Several types of pedogenic pools are known from Southern California. In all cases, they have developed over restrictive layers created as the soils have matured and which perch winter water near the soil surface.
Tectogenic	Tectonic activity has directly or indirectly created local sediment-filled depressions, which sustain vernal pools along active faults. The restrictive, or "perching" horizon supporting seasonal ponding is formed from lake sediments or ponded clays deposited in the tectonogenic depression, commonly over periods of thousands or tens of thousands of years. These pools tend to be among the largest and deepest, and are supported watersheds of (typically) 20 to 200 acres; they are distinguished by drawing much of their inflow from the steeper slopes with thinner soils near the edges of their watersheds rather than those surrounding the basin.
Landslide	A number of vernal pools have developed in depressions within or at the heads of landslides. As with the tectonogenic pools, inflow may originate from steeper areas at the edges of the contributing watershed, and are generally most vulnerable to changes and disturbance at the edges of their
Alluviated	Alluviated pools are formed when floodplain or natural-levee deposits left by floods on nearby streams or alluvial fans/aprons dam their outlets.
Dune dammed	Winds produce dunal depressions, which can develop into vernal pools. More commonly, it is dunes advancing over old terraces or floodplain can obstruct drainage and form dune-dammed pools. Some vernal pools are sharply elongated in the direction of the prevailing wind, presumably by waves. In many cases, the obstructing dunes or the eroding winds were formed under mid-Holocene or Pleistocene conditions, with soil-forming processes augmenting the pool-forming effects.
Bedrock	A few pools are not sedimentary – for example the tenajas of Riverside County or the tanques of the Santa Rosa Plateau, but these seem to be relatively rare in Southern California.

Major Vernal Pool Classes of Origin

Most southern Californian vernal pools are formed on sedimentary[2] (depositional) surfaces formed by (a) pedogenic processes in old soils, (b) movements along faults (in geologic parlance, "tectonic offset and co-seismic subsidence"), (c) landsliding, (d) alluviation or differential sedimentation along drainageways, and (e) dune-dammed pools formed by aeolian (windblown) scour or deposition. Although most pools have a clearly dominant genetic class, some have a compound origin involving forms and functions associated with two classes. Wind erosion can magnify effects of each.

Vernal pools formed on old terraces or crystalline bedrock deeply weathered by pedogenic processes are the most numerous and widespread (See Figure 3.2). Several types of pedogenic pools are known from southern California. In all cases, they have developed over restrictive layers created as the soils have matured and which perch winter water near the soil surface. Sometimes the restrictive layers are created by a claypan, formed by downward movement of clays and their accumulation in the subsoil ("illuviation") (Nikiforoff 1941). In other cases, the restrictive layers have formed as duripans of lime ("calcareous horizons" or, in some cases, "caliche") or iron-silica cementation ("ferricrete" or "silcrete") (*cf.*, Abbott 1984, Abbott and Fink 1975, Nikiforoff 1941). Pedogenic pools tend to be quite ancient, often developing on surfaces that are upwards—and often much upwards—of 100,000 years old. Pools of this type normally draw most of their inflow from rain on and near the pool surface, unless they are part of a vernal pool complex, where drainage from pools upstream may also contribute substantially.

Tectonic activity has directly or indirectly created local sediment-filled depressions that sustain vernal pools along active faults. Examples include Skunk Hollow in Riverside County, the Moorpark vernal pond in Ventura County, and one or two of the Chiquita Ridge pools in Orange County. The restrictive, or "perching" horizon supporting seasonal ponding is formed from lake sediments or ponded clays deposited in the tectonogenic depression, commonly over periods of thousands or tens of thousands of years. These pools tend to be among the largest and deepest, and are supported by watersheds of (typically) 20 to 200 acres. They are distinguished by drawing much of their inflow from the steeper slopes with thinner soils near the edges of their watersheds rather than those immediately surrounding the basin.

[2] A few pools are not sedimentary – for example the *tenajas* of Riverside County or the *tanques* of the Santa Rosa Plateau, but these seem to be relatively rare in southern California.

A number of vernal pools have developed in depressions within or at the heads of landslides. The southern Otay Mesa and most of the Chiquita Ridge/San Clemente pools share this origin. The landslides frequently develop in fractured mudstones or shales, often those assigned to the Monterey, Modelo or Otay formations, which tend to weather to heavy clays that deposit in and seal the depressions. As with the tectonogenic pools, inflows may originate from steeper areas at the edges of the contributing watershed, and are generally most vulnerable to changes and disturbance at the edges of their contributing area. We believe that many of these landslide occurred when sea level – and the valley floor adjacent to the slide – were lower during the glacial ages, mainly the most recent ones that peaked either about 18,000 or 55,000 years ago. The slides are relict from a former climate, but the ponding areas in their headscarps or in their toes remain.

Some pools are formed when floodplain or natural-levee deposits left by floods on nearby streams or alluvial fans/aprons dam their outlets. Examples of these alluviation **pools** include some of the lower-lying Ramona pools and the Fairview pool complex in Orange County. An active alluvial apron controls the depth of the Tierra Rejada pool in Moorpark, Ventura County (principally tectogenic). Many other seasonal or lagoonal wetlands throughout southern California are formed or governed by similar processes.

Winds produce dunal depressions, which can develop into vernal pools. More commonly, it is dunes advancing over old terraces or floodplain that obstruct drainage and form dune-dammed pools[3]. Some vernal pools are sharply elongated in the direction of the prevailing wind, presumably by waves. In many cases, the obstructing dunes or the eroding winds were formed under mid-Holocene or Pleistocene conditions, with soil-forming processes augmenting the pool-forming effects. Many of the Santa Barbara County pools (both Ellwood and Isla Vista) have been ponded in part by cliff-head dunes advancing over marine terraces, a pattern that may also occur at Carlsbad (Poinsettia Station) and elsewhere in San Diego County. Pools of this type normally draw most of their inflow from rain on and near the pool surface, with relatively less water contributed from outlying portions of the watershed—except for the once-encroaching dunes that tend to release rain slowly into the pools, especially late in the season. Hence, dune-dammed pools tend to be vulnerable to disturbance that compacts or covers the recharge areas in the dune deposits.

Describe the Recent Precipitation Regime

As indicated in earlier chapters, southern California's climate is highly variable both within and between years. Precipitation is so sparse and strongly seasonal that there is a substantial probability an assessment may be proposed when conditions are too dry for a full assessment. During the yearly drought period (summer) or in the rainy season of a dry year or after a string of drier-than-average

[3] See Joseph Silveira's "Vernal Pools and Relict Duneland at Arena Plains" in *Fremontia* (2000).

years, a full assessment employing direct observations of function is not possible (See "Direct and Indirect Data" section). The wetland edge cannot be reliably determined, prior- and current-year vegetation may be indistinguishable from one another and much or all of the characteristic flora and fauna could be dormant and cryptic. Indirect measures (microtopography, soil type, disturbance types and levels) can be taken regardless of moisture conditions. Direct measures (hydrology, biogeochemical processes and presence of characteristic plant and animal species) can only be fully assessed under specific conditions. Given the soil type and topography, ponding may be deemed likely after sufficient rainfall, but only the presence of standing water and a seasonal hydrograph can fully describe the pool's hydrological properties. Ponding can be affected by variables that cannot be assessed in the field. Examples would be "leaky bottoms," subsurface hydrological connections and soil profile anomalies. If there are multiple or long-duration ponding events, composition of the aquatic invertebrate fauna changes as the season progresses. One sample during the rainy season is inadequate to characterize the faunal composition. Plant species are less problematic if there has been sufficient moisture to trigger germination and sampling is done before the seasonal drought intensifies. Soil moisture buffers the aboveground variability due to sporadic rain events or early cessation of the seasonal rains.

Collection and Recording of Data

Information and data used to assess the functions of vernal pool depressional wetlands in southern California are collected at several different spatial scales. Data on landscape scale variables such as land use and catchment area should be collected from aerial photographs, maps and other sources prior to the site visit then confirmed on-site. Information about the WAA in general is collected during a walking reconnaissance of the WAA. Finally, detailed site-specific data are collected in and around each basin. If the WAA is large, detailed data should be collected from a number of representative locations throughout the WAA.

The exact number and location of these data collection points are dictated by the size and heterogeneity of the WAA. If the WAA is relatively small (*i.e.*, less than 2-3 acres) and homogeneous with respect to the characteristics and processes that influence vernal pool wetland function, then 3 or 4 basins representing different size classes and landscape positions are probably adequate to characterize the WAA. As the size and heterogeneity of the WAA increases, more basins are required to accurately represent the site. If sensitive or endangered species are potentially present, all basins will need to be assessed. Assessment of the hydrologic function, if appropriate for the WAA, will influence the choice of pools to be assessed.

As with defining the WAA, there is an element of subjectivity and practical limitations in determining the number of sample locations for collecting site-specific data. Experience has shown that, with adequate preparatory work, the time required to complete an assessment at a several-acre WAA is 2-4 hr for a team of 4-5 people. Training and experience will reduce the required time to the lower end of this range. The vernal pool flora and fauna include a wide array of species that vary depending on pool type and that require substantial expertise to sample and identify even under optimal conditions. Thus, additional training is required than would be necessary in less diverse and specialized wetland subclasses. Full identification of the aquatic invertebrate fauna would require laboratory analysis of the field samples. Skilled workers can process a sample in less than a day, but larger, more complex samples can take two days or more.

Direct and Indirect data

Indirect data can be taken at any time of the rainfall year (July 1-June 30) or in a run of dry or wet years. By definition, indirect data are taken on persistent indicators that have a strong correlation with actual function but do not directly measure the function itself. For example, a depression in a landscape with slope <5%, combined with an undisturbed soil profile having drainage-impeding layers, is likely to pond water during the rainy season (Bauder and McMillan 1998). However, direct observation of the water storage function must be taken on actual ponding events (depth, number and duration) and presented as a seasonal hydrograph.

Full functional assessments employ direct data, and they cannot be made unless there has been sufficient precipitation to elicit the responses being assessed (Table 5.4). In order to decide whether or not conditions for the collection of direct data have been met, the appropriate sections on the Pool Scale Base Map data form need to be completed (Appendix C.2) using the Precipitation Regime Context and Data Collection Guidelines (Appendix D.1). At a minimum, there must be one ponding event of at least 48 hours duration to demonstrate a basin's ability to hold water. To support a full life cycle for San Diego fairy shrimp, at least ten consecutive days of ponding are usually required. Water temperatures affect the required ponding duration by impacting developmental rates, especially of the aquatic fauna.

Germination of much of the characteristic vernal pool flora occurs without ponding if soils are sufficiently moist, but some annuals may require standing water, however shallow (Bauder 1992). Many plant species commonly associated with coastal San Diego vernal pools do not germinate during dry winters that tend to be warmer as well (Bauder 2000). Herbaceous perennials may not resume growth in very dry years. If rainfall is sparse, the window of opportunity for proper identification of

Table 5.4. Conditions for Collection of Data to Make Direct Estimates of Function*

Function 1 Surface and Sub-surface Water Storage

The water storage function can only be estimated directly in years with total seasonal precipitation ≥ 14 cm. There must be at least one ponding event ≥ 48 hours.

Function 2 Hydrologic Networks

A minimum of 5 cm of precipitation in a two-week period is usually required to trigger ponding in pools at lower elevations in a network, an additional 4-5 cm for ponding in mid-network basins, and another 4-5 cm to fill basins in the entire network, from highest to lowest elevation. This was tested in a network of 10 pools with a maximum linear drainage pathway of 105 m and a drop in elevation of 0.88 m from the bottom of the highest pool in the network to bottom of the lowest pool. Hydrological data taken over a 20-year period in coastal pools on soils of pedogenic origin were supplemented by intense monitoring of the entire network during one year. Surface hydrologic networks are rarely evident in dry years (<25 cm of seasonal precipitation).

Function 3 Biogeochemical Processes

Unknown

Function 4 Maintenance of the Characteristic Plant Community

If water is standing too deeply or the dry phase succeeds a year of below average precipitation, direct evaluation of function cannot successfully be estimated. In drier-than-average rainfall years, some important species may not germinate or renew growth, or be depauperate or fail to flower if they do grow. These conditions result in a telescoped field season and difficulty in identifying species. Given the extreme variability of the climate, pools will need to be surveyed in at least two separate years to estimate this function directly.

Function 5 Maintenance of the Characteristic Faunal Community

The faunal index can only be estimated directly if the maximum depth of the basin is ≥ 0.07 m and there must be continuous ponding for ≥ 2 weeks. For indirect assessment, the maximum depth of the pool must be ≥ 0.15 m. For full direct community assessment, repeat samples throughout the season must be collected.

***These guidelines have been developed and tested on vernal pools in coastal San Diego on soils of pedogenic origin. They may or may not apply to other pool types (age and origin) in different locations (sub-regional climates).**

key species that have germinated or initiated growth may be very narrow and require years of observations spanning an array of precipitation regimes, both in total amount and pattern of rainfall.

Detailed specifications for the collection of direct data are discussed in the sub-section devoted to direct data collection.

Collection of Indirect Data

<u>Construction of On-site Base Maps</u>

Landscape Scale Base Map

Site characterization begins with the preparation of base maps for each WAA or PWAA. The objective in the development of the landscape-scale base map(s) is to (a) measure the aerial extent of the current type and level of disturbance in and around the WAA, and (b) place the wetlands in context, noting important landscape features such as drainage networks, roads, culverts, water control structures and signs of past land use such as fire, tillage, type conversion or grazing. Base maps should initially be developed in the office from preexisting maps, aerial photographs or digital elevation models (DEMs). In order to assess landscape level disturbances, the base map should extend in a circle (1 km radius) centered on each pool. Wetland delineation maps may exist that have been completed for the WAA, or such delineation can be integrated into this procedure. Use Table 5.5 as a guide to the types of disturbance that need to be documented in order to score each basin for its landscape-level disturbance. A more detailed list of disturbances levels and types can be found in Appendix D.2.

On the landscape map/photo/DEM (or LiDAR):

- Identify approximate pool boundaries and shapes on aerial photos, if possible
- Identify surrounding drainage networks, including swales, channels, and inferred flow directions
- If present, indicate disturbance areas that may affect drainage directions, including signs of fire, cattle grazing or subtle evidence of tillage, of managed vegetation ("chaining" or mechanical conversion to grasslands) or trenching for pipelines.

Pool Scale Base Map

The development of accurate base maps for the individual pools is important to the assessment of a number of variables and thus must be done accurately and precisely. Using the methods described below, complete the Pool Scale Base Map Data Form (Appendix C.2). Complete a sketch of the pool, as outlined in the final step below.

- Using a GPS receiver, record latitude/longitude in the deepest area of the pool.

- Evaluate the inlets, outlets and connections.
  Is a visible surface inlet(s) present? If so, is the inlet(s) a defined channel (with a distinct bed and banks) or a swale (depression without a bed and banks)? Do the inlet(s) appear to be modified? Is an outlet present? More than one? If so, has it/they been modified? How is the inlet supplied? Where does the outlet lead? Are there other pools?

- Evaluate the catchment area

  Starting at the outlet, walk along drainage divide, marking the divide periodically with flagging. Continue around perimeter of pool catchment area until arriving back at opposite side of outlet.

  Sketch catchment perimeter on aerial photograph, designating areas of uncertainty, if any.

  Measure (pace or with tape measure) long and short axes of the catchment to develop an initial estimate of the catchment area. Record the estimate, and keep it in mind during subsequent fieldwork.

  Set the GPS receiver to 'track', and re-walk the catchment perimeter, so the GPS unit records the perimeter. Re-evaluate the chosen drainage divides as you walk, removing flagging as you go.

  In the office, plot GPS track and calculate area (by planimeter, GIS or measuring length and width in mapping software).

Table 5.5. Disturbance Categories

Category	Description*
1	minimal disturbance/no disturbance
2	light to moderate disturbance --not recent, self-recovered or restorable
3	moderate to substantial disturbance --restorable or has been restored; some potential for self-recovery
4	substantial disturbance--restoration potential, but extensive restoration efforts needed
5	substantial disturbance--developed or restoration potential low
6	severe disturbance—surrounding landscape dominated by development;restoration potential minimal to none

*For more complete descriptions see Appendix D.2.

- Establish the following relative elevations using hand-level (or auto-level) and stadia rod and recording elevations on the worksheet

  Outlet(s)

  Deepest location in the pool

  Record maximum depth (Outlet depth minus deepest location in the pool)

- Define pool edge

  A distinct edge may be marked by an abrupt change in the presence or absence of algae and/or debris, vegetation, cobble density, or soil color over a very small distance (~10 cm in small pools to 1 m in large pools) around the majority of the pool perimeter. An indistinct edge does not show a contrast in these features over a small area.

If the edge is indistinct, and the outlet is present, use the elevation of the outlet to establish the edge elevation.

- Establish long and short axes of the pool

  Note: these axes will be used to calculate area and volume, and should reflect the average length and width. Therefore, the ends of each tape measure will not necessarily be at the pool edge.

  Hammer spikes or short rebar at either end of both axes, and attach tape measure, pull tight.

  Record long axis length and short axis length.

  Using calculator, calculate long axis slope, pool area, and pool volume.

  Using compass set to the local declination, record heading of long axis.

- Sketch pool

  If an aerial photograph is at an appropriate scale, sketch directly onto the photo.

  If an aerial photograph is not available, sketch the pool on graph paper, to scale.

  Leave long axis tape measure in place. Using short axis (or a third) tape, record distance to edges of pool at stations along the long axis.

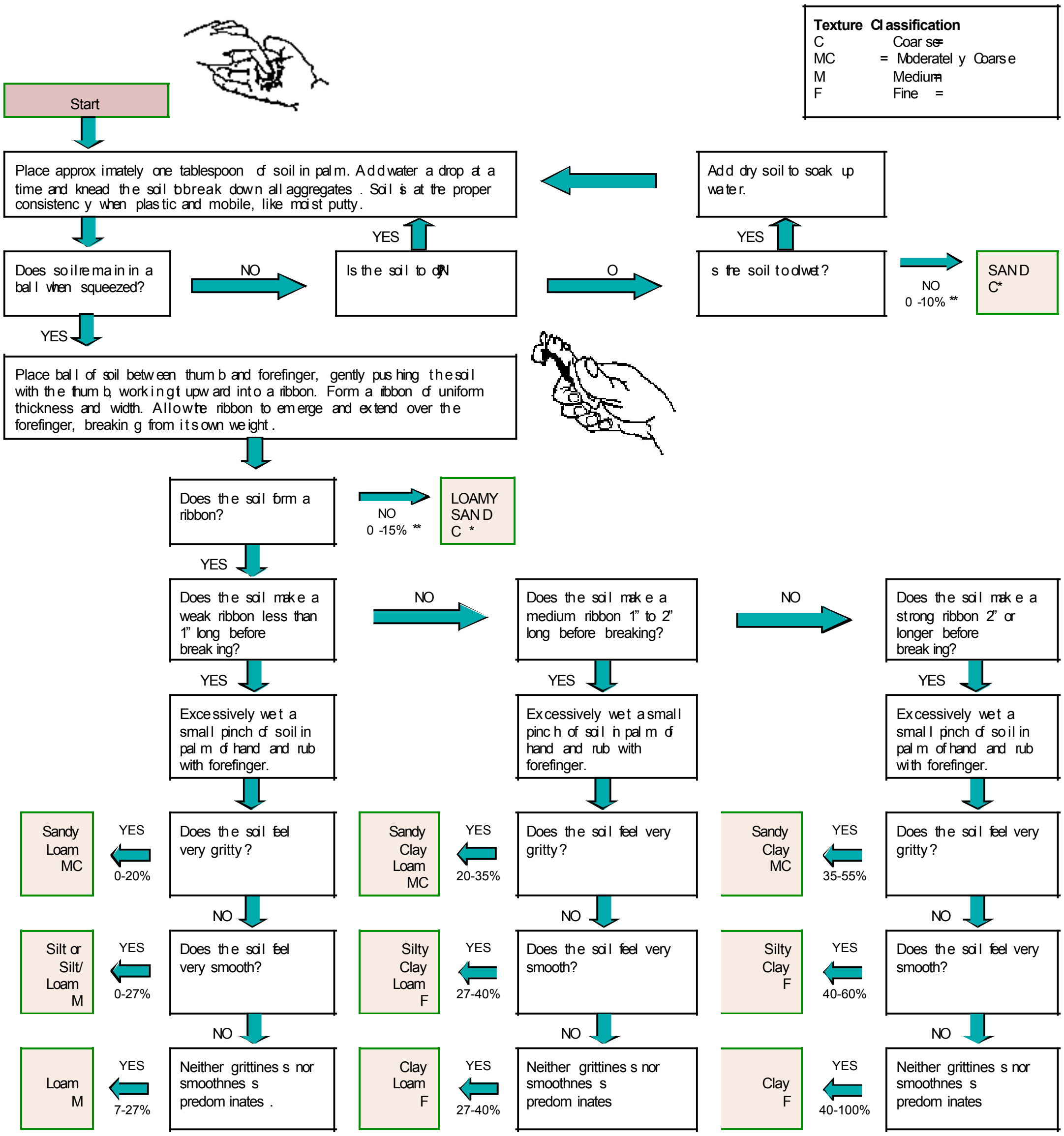
  Show locations of inlet(s), outlet(s), mounds, vegetation communities, surface cracks, sediment scour or deposition areas, areas and types of disturbance, algal mats, high water marks and/or pool edge-defining features.

Evaluation of Soils

- With hand trowel, excavate small pit (3-4 inches deep)
- Classify soils according to NRCS classification system (soil order)
- Conduct 'feel test' to establish texture of the matrix, using the method outlined in Figure 5.5.

Record the result on the Pool Scale Base Map Data Form (Appendix C.2).

More detailed examination of soils along transects from the uplands into the pool basins would be warranted if 1) endangered species with specific soil affinities are present or the habitat is being restored to support them, or 2) confirmation of the presence or loss of a natural gradient in soil texture and nutrients from the uplands into the basin is one of the goals of the assessment. Species distributions within basins correlate with factors related to a pool-scale elevational gradient, including various soil attributes and length of inundation (Bauder 1987a). At a larger scale, they correlate with soil series (Bauder and McMillan 1998).



* Sand Particle size should be estimated (very fine, fine, medium, coarse) for these textures. Individual grains of very fine sand are not visible without magnification and there is a gritty feeling to a very small sample ground between the teeth. Some fine sand particles may be just visible. Medium sand particles are easily visible. Examples of sand size descriptions where one size is predominant are; very fine sand, fine sandy loam, loamy coarse sand.

** Clay percentage range.

Modified from: Thien, Steven J., Kansas state University, 1979 Jour. Agronomy education.

Figure 5.5. Determining soil texture by the "feel method."

Examination of Surface Features

The basin is defined as a topographic depression that ponds water given sufficient rainfall. It comprises the area below the lowest outlet elevation. The periphery is a 20-ft (c. 6 m) wide band extending around and parallel to the edge of the basin. The edge of the basin is equivalent to the elevation of standing water when the basin is filled to capacity or overflowing. The catchment area is the watershed that topographically can contribute to the basin under existing conditions. If the catchment has recently been modified, the original catchment should be estimated, where feasible. It may contain one or more pools.   Use the Pool Scale Base Map Data Form (Appendix C.2) to record the following observations on the surface features of the basin, its periphery and catchment.

Basin

- Sediment

  Describe the texture of sediment (a) recently deposited in the pool, and (b) which may be present in any deltas or deposition at the pool inlet. See above for description of soils.

- Cobbles

  Estimate the percent cover of angular, coarse pebbles, cobbles or other discrete larger clasts; these will usually be dispersed at near-equal distances over the bed of the pool (probably a result of shrink-swell of the soils over many years). Pebbles are 2-7.5 cm in diameter and cobbles are 7.5-25 cm in diameter (soil Survey Manual 1993).

- Cracks

  Record the presence of soil cracks (shallow or deep) or their absence. Deep cracks are > 1cm wide and over 1 dm deep.

- Disturbance

  Characterize the location, depth, and percent cover of evidence of any tillage or construction-related disturbance of the restrictive horizon supporting ponding; evidence of trenching (such as for utility lines); ruts or tire tracks that have compacted the soil surface; or fences crossing though the basin or anthropogenic debris in the basin. Appendix D.2 should be used as a guide for the type and level of disturbance that need to be recorded. Record the dominant disturbance for the basin.

Periphery and Catchment

- Disturbance

  Characterize the location, depth and percent cover of disturbance due to tillage, grazing, brushing, trenching (such as for utility lines), bladed roads, hard surfaces, land leveling or ripping, quarrying and artificial landscapes. Appendix D.2 should be used as a guide for the type and level of disturbance that need to be recorded. Record the dominant disturbance for the periphery and the catchment.

- Mounds

  Are mounds present or absent?

<u>Assessment of Disturbance Levels</u>

The basin, periphery and catchment are assessed for the dominant disturbance (Table 5.5, Pool Scale Base Map Data Form Appendix C.2 and Appendix D.2). Entries for the dominant disturbances are the category (1-6) that best describes the condition of the greatest part of the basin, periphery or catchment.

Landscape-level disturbance is assessed in four separate quadrants, using the same disturbance categories as above. The quadrants are 90-degree wedges of a circle (radius = 1 km) centered in the basin. Quadrant 1 = 0-90 degrees, 2 = 90-180 degrees, 3 = 180-270 degrees, and 4= 270-360 degrees. Depending on the WAA, the Landscape-level disturbance scores may be determined in the field using the Landscape-level map or in the office using an aerial photograph. If using the latter, construct an outline of a circle with a radius of 1 km based on the scale of the aerial photograph. Divide the circle into four wedges. Locate each pool in the WAA and place the center of the circle over the middle of each pool and determine the score for each quadrant (Appendix C.3). Disturbance scores are computed by assigning a disturbance category to the entire quadrant (if relatively uniform) or portions of the quadrant and then multiplying by the fraction of the quadrant in this condition if the quadrant is heterogeneous. All sub-scores are then summed to characterize the entire quadrant. For example: 0.50 x 1 + 0.25 x 3 + 0.25 x 5 = 3.50. The minimum disturbance score = 1.0 and the maximum = 6.0. Additional sample calculations are included in Appendix D.2.

Collection of Direct Data

Hydrology

Mark the pool with a rebar (projecting about 30 to 45 cm above the surface) and a metal tag with a unique number, if more than one pool is being followed. Firmly embed the rebar at the lowest elevation in the pool basin, as determined by the microtopographic studies for the base map. Affix a staff plate, visitube[4], ruler, or other vertical measure of sufficient clarity such that depths can be easily read from the shore when the pond is full.[5] The rebar-mounted measure can be used to record maximum pool depth at any given time, as well as provide a clear identifier for the pool. On windy days, water levels should be read at mid level, or midway between the highest and lowest levels observed over a period of time; capillary rise or meniscus effects on the depth reading should be ignored or discounted by the observer.

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[4] Visitubes are machined lengths of clear polycarbonate tubing, scribed at intervals of 0.10 feet, which allow observers to measure not only the depth at the time of observation, but also to note the high-water mark for the storm(s) since the last visit (*c.f.*, White and Hecht 1994). Placing sieved burned cork on the inside of the tubing preserves high-water marks. The cork rises with rising waters in the pool, and then leaves a 'bathtub ring' as the level of the water subsides. The ring can be quickly erased with a swipe from a drugstore bottlebrush or a squirt from a water bottle, resetting the tube for subsequent storms. Cork is replenished as needed, usually once or twice per season. The visitube functions in much the same manner as the crest-stage gauges that have been used for decades by hydrologists on rivers and lakes.

[5] Entering pools when ponded inevitably disrupts the pools and should be avoided, especially for routine measurements. Using an easily read staff plate or visitube, mounted with forethought for observation when ponded, can minimize pool entry; use of binoculars is often helpful, especially if also reading high-water marks. If more than one pool is being followed, plastic bags will be used to cover the data collector's shoes if the pool **must** be entered, and bags will be changed between pools. This prevents the transfer of seeds and cysts between pools.

Water depth will be measured 24 hours after the end of a major storm (c. 0.5 in/1.3 cm of precipitation), and every 3-5 days thereafter until the pool has drained (Bauder 1987a, 2005). Enter data into the Hydrology Direct Assessment Data Form (Appendix C.4).

Automated data collection using dataloggers and probes (or other sensors) can be used to determine water levels. For vernal pools, data should be recorded and stored at 15-minute intervals, or more frequently. Many different types of dataloggers and probes are manufactured, and any field-resilient data-collection array capable of measuring level will likely prove suitable, provided that sufficient field observations are made to validate the data. Measurement frequencies listed above for depth are a minimum for sufficient data to validate the electronic record. Data will be used to develop seasonal hydrographs and establish the hydroperiod. The choice of whether to install a datalogger and appropriate probes will depend upon the type of pool, the nature of the disturbance, and the number of pools at risk.[6] Dataloggers can also be used to characterize event and seasonal changes in salinity (specific conductance) and water temperature. These variables were not used in our model for the Surface and Sub-surface Water Storage function but they can be important in identifying factors that affect the growth rate and mortality of vernal pool invertebrates and in describing linkages between pools in a network or disruption of network connections.

With the exception of bedrock pools and tanques, water moves between pools and their banks in all types of southern Californian vernal pools. Where there is reason to expect or document changes in this function, mini-piezometers will be installed (or alternate means, such as geophysical methods). Such methods will be needed where there is reason to inquire into past or future changes in bank properties, such as heavy compaction or deep trenching within 30 feet of a pool. Piezometers will be installed to the depth of the first restrictive layer, and founded in it. The distance between the pool and mini-piezometer should be no more than 30 feet; experience has shown that distances of 5 to 15 are often most informative in the soil types prevalent in southern California *(c.f.*, Napolitano and Hecht 1991). They will have a perforated zone no thinner than 0.5 feet (15 cm), and an open bottom in contact with the restrictive layer. They will be constructed of casing of a minimum 2-inch diameter, and capped with material compatible with their casing. The annulus between the borehole walls and casing will be filled with sand opposite the perforations, and will be sealed with compacted native clays or bentonite, or as otherwise required by the local county code. The casing shall have a clear mark (reference point, or RP) at its northern tangent from which water-level measurements can be made. The RP shall be surveyed to the staff plate or other depth measure such that water levels may be

[6] We believe that the current standard in southern California now calls for installing an automatic data collection system if a group of more than 3 to 5 pools is being evaluated. Automated systems can also be used on individual pools if so warranted (See Hecht *et al.* 1998; Rains *et al.* 2006).

related to the water levels in the well to the nearest 0.01 feet. With a minimum 2" casing, specific conductance[7] and water temperature measurements may be made using hand meters.

Hydrologic Network(s)

Using the pool scale base maps, draw the catchment area boundaries of each network on the Landscape Scale Base Map. Give each network a unique number, if the WAA has more than one network. Count the number of pools in the network and fill in the Hydrologic Network Data Form (Appendix C.5.)

Complete the Hydrologic Network Data Form with data collected for the Pool Scale Base Maps. If a direct assessment is being made, complete the direct assessment portion of the data form with data collected for the hydrology direct assessment.

Vegetation/Plant Community

Preparation Prior to Fieldwork

Prior to field work, a list of important species that are potentially present in the WAA should be compiled, including all species in Distribution Categories 1-3 listed in Table 5.6, as well as species in Sections A and B of Appendix D.3. Each species should be assigned to a Distribution Category (Table 5.6). If the assessment is being done in a different pool type than one of those used to calibrate this model, the species lists will differ from those used for this analysis. For our analysis, we employed data collected from the central San Diego mesas (Kearny Mesa, Clairemont Mesa and Penasquitos), and two pool types each in Ramona and Otay Mesa (Table 5.2). Suggested sources for species locations, distributions and soil associations are listed in Table 5.7. Field work should be conducted according to the "Guidelines for Assessing the Effects of Proposed Projects on Rare, Threatened, and Endangered Plants and Natural Communities" published by the California Department of Fish and Game (Appendix D.4). Additional information on "Special Plants" (all the plant taxa inventoried by the California Department of Fish and Game's Natural Diversity Data Base) can be found in Appendix D.5. When the species list is complete, species names can be entered into the blank Vegetation Direct Assessment Data Form (Appendix C.6), leaving space for additional species identified in the field, or species names can be entered as they are encountered in the field.

[7] Specific conductance, electrical conductance and electrical conductivity are terms that are functionally synonymous and may be used interchangeably for the purposes of this guidebook. Specific conductance is used preferentially in this document, especially where use of this term can avoid confusion with hydraulic conductivity (permeability).

Field survey

Using the "Pool Scale Base Map," become familiar with the location of the edge of the basin (See Pool Scale Base Map, paragraph e). As a species is identified in the field, its name should be entered into the Species column and its Distribution Category should be entered into the BA (basin) and/or PERI (periphery) location column as appropriate. For example, if *Pogogyne abramsii* (San Diego mesa mint) is found within the basin, a 1 should be entered in the BA column. If it is found above the basin's edge in the 20-ft band surrounding the pool, the 1 should be entered in the PERI column. If it is found in both areas, both BA and PERI columns would be filled in with 1's. For the purposes of this study, the UPLAND plant species are those found in the basin's peripheral band and that are usually found in uplands, as defined by the U.S. Fish and Wildlife Service indicator categories: FACU (Facultative Upland) or UPL (Obligate Upland) (Fish and Wildlife Service 1996).

Table 5.6. Plant Distribution Categories
1= **listed**; endangered, threatened or rare (State or Federal list)(excluding category 6). 2**= narrow endemic**; native to an area south of the TransverseRanges in California, including **Baja MX (excluding category 6).** **3**= **regional**; native to the California Floristic Province (excluding category 6). **4**= **New World, Mediterranean climate**; native to the west coast of N/S America (excluding category 6). **5**= **cosmopolitan**; distributed east of the Sierras and/or worldwide, in addition to southern California (excluding category 6). No known introduction into southern California. **6**= **encroaching upland**; species from categories 1-5 that is found in the pool basin but usually occurs in the uplands. **7**= **introduced**; known introduction into California.
Definitions and assignments to distribution categories are based primarily on Hickman, James C., ed. 1993. The Jepson manual: Higher plants of California, University of California Press, Berkeley, CA.

Table 5.7. Suggested Resources for Information on Species Distributions and Soil Affinities
US Fish and Wildlife Service—Carlsbad and Ventura Field Offices
USDA/NRCS—"Soils" website
US Forest Service
California Department of Fish and Game California Natural Diversity Data Base Resource Management—Habitat Conservation Regional offices
California Department of Parks and Recreation—appropriate districts
City of San Diego—Planning Department
County of San Diego—Planning and Land Use Department
SANDAG (San Diego Association of Governments)
San Diego State University Herbarium
San Diego Natural History Museum
California Native Plant Society local chapters vernalpools.org website
Environmental consulting firms
University faculty/researchers

Faunal/Aquatic Invertebrate Community

Sample pool for crustaceans during the wet phase as follows:

Sampling regime

- During the first inundation event of the wet season, the pool should be sampled 10 days from the start of inundation. (The pool must have continuously held water during these 10 days. If the pool dries prior to 10 days, that inundation event cannot be used for direct faunal assessment.)
- Sampling cannot be conducted while it is raining, as crustaceans hide on the bottom due to the surface disturbance. If it is raining on day 10, sampling may be delayed until days 11-14.
- Pool should be sampled every 10 days thereafter until there is no standing water, up to a maximum of three months. (If necessary due to weather, the interval between sampling events may be increased to a maximum of 14 days.)

  Sampling will be repeated for all inundation events throughout the wet season to accurately characterize the full crustacean community.

Sampling will need to be extended to a second year if:

> $V_{MAXDEPTH}$ < 0.15 m and < 2 samples were taken during the year. (These samples may be from the same or different inundation events.)
>
> $V_{MAXDEPTH} \geq$ 0.15 m and < 3 samples were taken during the year. (These samples may be from the same or different inundation events.)

Field methods

- If pool is < 0.30 m deep at the time of sampling, 1 sample (consisting of 3 net sweeps) will be taken as described below.

- If pool is ≥ 0.30 m deep at the time of sampling, 1 sample (3 net sweeps each) will be taken from each of the following locations:

  Deep water (benthic) sample from the deepest portion of the pool

  Just under the surface to middle depths

  Edge of pool

- For each crustacean sample, sweep a standard aquarium hand net through the pool three times (1.0 meter length each) in different locations. If a 1.0-meter sweep is not possible because the pool is too small, the sweep should be as long as possible. Net size (rectangular surface area) should be 10-15 cm^2, although nets as small as 5 cm^2 may be used when there is little standing water. Net should be placed vertically into pond, and very lightly bounced along bottom throughout the sweep.
- Using the crustacean data sampling form (Appendix C.7), record the depth that the net sampled, so that the volume of water sampled may be calculated.
- If the pool is exceptionally shallow, a known volume of water may be scooped out with a small cup and poured through the aquarium net.
- Rinse all material out of net with carbonated soda water (to anaesthetize animals) into a single twirl-top bag, large vial or collection jar. Combine material from all sweeps on the same date into the same bag. Carefully decant all carbonated water. A small, fine sieve may be useful. For samples with significant amounts of algae, add enough 95-100% ethyl alcohol to dilute the sample to approx. 80% ethanol. For samples with little or no algae, fill bag with 80% ethanol. This is best accomplished with a standard laboratory squirt bottle, and small sieve with mesh that at least as fine as the aquarium net. If a vial is used, a funnel with a large opening may be useful.

Laboratory methods

- Within 24 hours of field collection, replace all liquid with 70% ethyl alcohol / 25% water / 5% glycerin in the laboratory. Samples may be stored indefinitely thereafter.
- Separate crustaceans from other material under a dissecting microscope, and sort to species according to Balcer et al (1984), Belk (1975), Cohen (1982), Fugate (1993), Pennak (1989), and Thorpe and Covich (1991). A sufficiently trained taxonomic expert may be able to distinguish more than one morphotype of some cladocerans and ostracods that likely correspond to species. Several unnamed ostracod species are known to exist in pools within the reference area.

All identified crustaceans should be archived for review and possible future research, in properly labeled and curated vials or jars.

SAMPLE LABEL:

Crustacea: Cladocera: *Ceriodaphnia dubia* M011205-2 Marine Corps Air Station Miramar San Diego County, CA HGM pool 29 (complex AA9, pool 139W) coll. 12 January 2005, M. Simovich det. 25 March 2005, M. Simovich

- A reference collection for all samples in a single project should be available for external review upon request, containing up to 5 individuals per species in separate vials. Documentation should be retained that relates individuals in the reference collection to specific ponds and collection dates.
- Taxonomic identifications should be verified with a reference collection maintained by USFWS.
- $V_{CRUSTSPP}$ = the total number of crustacean species identified from all samples and all inundation events, reflecting the complete species list for the pool

Analytical Techniques and Procedures

A variety of methods have been use to develop HGM guidebooks, with a general approach (Butterwick 1998, Smith and Wakeley 2001) as follows:

a. Define inherent functions provided by the habitat

b. Define variables that may relate to one or more functions in a direct (causative) or indirect (statistical, correlative) manner

c. Define one or more Functional Capacity Indices (FCIs) per function using a subset of the variables in an equation, where 0 indicates no function, and 1 indicates the highest possible function.

Criteria used to choose among potential variables and quantitative development of FCIs are rarely addressed in any detail in HGM guidebooks. In practice, many FCIs may be developed based on best expert opinion, without any underlying statistical justification.

Techniques and Procedures Used in developing the Functional Capacity Indices for this Guidebook

For developing this guidebook, we sought whenever possible to take the following approach:

a. Choose a set of 61 pools from across San Diego County that span a full range of functionality and disturbance levels.

b. Collect field data on variables that causally relate to pool function from 28-61 pools, depending on the function.

c. Develop a Direct FCI for each function as follows:

- •1 Using best expert opinion, designate *a priori* a subset of pools that has the highest overall functionality (reference standards), and a subset that has the lowest function.

- •2 Using exploratory data analysis (*e.g.*, examination of scatterplots and boxplots, bivariate correlations, search for natural inflections or breakpoints in the data), ordination, and general linear modeling, develop a preliminary Direct FCI. In this preliminary analysis, only pools chosen in *c*1) were used. The reference standards received an *a priori* FCI of 1, and the lowest function pools received an *a priori* FCI between 0 and 0.25, depending on their status. These FCI scores were consistent with the FCI definitions provided in Appendix D.6. The result was a statistical model in which Direct FCI is calculated as a linear combination of categorical and/or continuous variables that clearly relate to the specific function.

- •3 Validate and calibrate the preliminary Direct FCI on the full set of 61 pools (28-61, depending on the function) using best expert opinion. In this phase, further exploratory data analysis was used to make adjustments to model parameters.

- •4 The Direct FCI is considered to be the best way to assess pool function, although it may not be possible to score it during all seasons of the year. The Direct FCI may also require additional effort and expertise that is not required for the indirect FCI.

d. Develop an Indirect FCI for each function as follows:

- •1 Calculate the Direct FCI for each pool in which appropriate data have been gathered.

- •2 Using exploratory data analysis (*e.g.*, examination of scatterplots and boxplots, bivariate correlations, search for natural inflections or breakpoints in the data), ordination, and general linear modeling, develop a preliminary Indirect FCI. This was estimated as a general linear model in a manner similar to *c*2) above. However, the dependent variable in *c*2) is *a priori* Direct FCI, whereas the dependent variable in *d*2) is the final calibrated Direct FCI from *c*3) above. The independent variables (predictors) in *c*2) are a small set of field-measured variables that directly relate to the function. In contrast, the independent variables in *d*2) are variables that can be measured in the field by any qualified scientist or contractor, in a short time using relatively simple field equipment, during either the wet or the dry phase of the pool.

- •3 Validate and calibrate the preliminary Indirect FCI on the full set of 61 pools using best expert opinion. In this phase, further exploratory data analysis was used to make adjustments to model parameters.

- •4 The Indirect FCI is considered to be a more rapid way to assess pool function than the Direct FCI, and the Indirect FCI may be calculated at any time of year. However, this convenience comes at the cost of reduced accuracy.

We were unable to take this approach with all functions, due to a lack of high quality data to develop the Direct FCI for some functions. As in other published guidebooks, best expert opinion was used in these cases. The following table summarizes the approach used for each function:

Table 5.8. Number of Pools Used for Development of Direct and Indirect FCIs.		
Function	**Direct FCI development**	**Indirect FCI development**
Surface and Sub-surface Water Storage	45 pools	61 pools
Hydrologic Networks	3 networks	3 networks
Biogeochemical Processes	n/a	n/a
Maintenance of the Characteristic Plant Community	61 pools	61 pools
Maintenance of the Characteristic Faunal Community	28 pools	61 pools

Tables containing the data used for the analyses are available upon request.

Application of the Results of the Assessment

Once the assessment and analysis phases are complete, the results can be used to compare the same wetland assessment area at different points in time, comparing different wetland assessment areas at the same point in time, comparing different alternatives to a project, or comparing different hydrogeomorphic classes or subclasses as per Smith *et al.* (1995).

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Appendix A
Glossary

Abiotic: Not biological.

A Horizon: A mineral soil horizon at the soil surface or below the O horizon characterized by accumulation of humified organic matter intricately mixed with the mineral fraction.

Alien Species: not native; introduced purposely or accidentally into an area. See "The Jepson Manual: Higher Plants of California" (Hickman 1993)[1].

Alluviated Basin Origin: Basins or pools formed by alluvial (channel) deposition across their outlets. Such deposition is typically overbank sediment or natural levees formed during floods, often where a large stream with high sediment loads leaves deposits too extensive for a small tributary to cut through. A southern California type locality: several pools in the Ramona area on the floodplain of the larger local streams.

Assessment Model: A simple model that defines that relationship between 1) ecosystem and landscape scale variables and 2) functional capacity of a wetland. The model is developed and calibrated using reference wetlands from a reference domain.

Assessment Objective: The reason for conducting an assessment of wetlands functions. Assessment objectives normally fall into one of three categories. These include: documenting existing conditions, comparing different wetlands at the same point in time (i.e., alternatives analysis) and comparing the same wetland at different points in time (i.e., impact analysis or mitigation success).

Assessment Team (A-Team): An interdisciplinary group of regional and local scientists responsible for classification of wetlands within a region, identification of reference wetlands, construction of assessment models, definition of reference standards, and calibration of assessment models.

Bare Ground: basin surface without vegetation, thatch or cobbles.

Basin: The topographic low in which a vernal pool forms. Basins are typically taken to be the entire pool area below its sill, or 'spill elevation,' at its outlet.

Basin Edge: Maximum elevation of ponding based on the expected 10-yr rainfall event.

Basin Periphery: A 20-ft band surrounding the edge of the basin.

Bedrock: The solid rock that underlies the soil and other unconsolidated material or that is exposed at the surface. See "Soil Survey of San Diego Area, California" (Bowman 1973).

Bedrock Basin Origin: Basins or pools formed in bedrock settings in which the bedrock itself is the restrictive unit. Bedrock basins are typically formed by wind or by dissolution. Type localities in southern California: various tinajas.

[1] References cited in this appendix are in References section following main text.

Biotic: Of or pertaining to life; biological.

California Floristic Province: All of California west of the dry regions of the Great Basin and the deserts and extending into southwestern Oregon and northwestern Baja California, MX. See “The Jepson Manual: Higher Plants of California” (Hickman 1993).

Catchment Area: An area from which surface water flows to a pond, channel or other surface hydrologic feature. Synonyms are ‘drainage basin’ or ‘watershed’. (Modified from Gary et al. 1972.)

Claypan: A compact, slowly permeable soil horizon that contains more clay than the horizon above and below it. A claypan is commonly hard when dry and plastic or stiff when wet. See “Soil Survey of San Diego Area, California” (Bowman 1973).

Contributing Area: Hydrologically, an area from which groundwater percolates to a pond, spring, channel or wetland area; it is usually, but not always, the same as ‘catchment area,’ drainage basin,’ or ‘watershed,’ but can differ substantially in certain geomorphic environments, such as near dunes, sandy soils or pools of tectogenic or landslide origin.

Crustacean: Any mainly aquatic arthropod usually having a segmented body and chitinous exoskeleton. A member of the class Crustacea.

Cyst: Encysted, dormant life history stage of an aquatic invertebrate. May be an egg, embryo or other stage.

Direct Impacts: Project impacts that result from direct physical alteration of a wetland (*e.g.*, the placement of dredge or fill).

Depressional Wetland: A wetland that occurs in a topographical depression with a closed elevation contour that allows accumulation of surface water. Dominant sources of water are precipitation, groundwater discharge and interflow from adjacent uplands. Direction of water movement is normally from the surrounding uplands toward the center of the depression. See “An Approach for Assessing Wetland Functions Using Hydrogeomorphic Classification, Reference Wetlands, and Functional Indices” (Smith et al. 1995).

Direct Measure: A quantitative measure of an assessment model variable.

Dune Dammed Basin Origin: A basin or pool impounded by dunes or other aeolian deposits across a drainageway or swale. Type localities in southern California: Poinsettia Lane in Carlsbad (San Diego County) or the Ellwood Beach pools near the existing bluff (Santa Barbara County).

Endemic Species: native/indigenous species usually confined to a very restricted geographical area or region. See ”A Dictionary of Botany” (Little and Jones 1980).

Exotic (non-native/introduced/alien) species: See alien species above.

Flowthrough Basin: a basin with both an inlet and an outlet.

Facultative (FAC): Equally likely to occur in wetlands or non-wetlands (estimated probability 34-66 percent)(Fish and Wildlife Service 1996).

Facultative Wetland (FACW): Usually occurs in wetlands (estimated probability 67-99 percent), but occasionally found in non-wetlands)(Fish and Wildlife Service 1996).

Functional Assessment: The process by which the capacity of a wetland to perform a function is measured. The approach measures capacity using an assessment model to determine a functional capacity index.

Functional Capacity: The rate or magnitude at which a wetland ecosystem performs a function. Functional capacity is dictated by characteristics of the wetland ecosystem and the surrounding landscape and interaction between the two.

Functional Capacity Index (FCI): An index of the capacity of a wetland to perform a function relative to other wetlands from a regional wetland subclass in a reference domain. Functional capacity indices are by definition scaled from 0.0 to 1.0. An index of 1.0 indicates that the wetland performs a function at the highest sustainable functional capacity, the level equivalent to a wetland under reference standard conditions in a reference domain. An index of 0.0 indicates that the wetland does not perform the function at a measurable level, and will not recover the capacity to perform the function through natural processes.

Geographic Subregion: physiographic and biologic region of California based on topographic, climatic and plant-community variations. See "The Jepson Manual: Higher Plants of California" (Hickman 1993).

Geomorphic: Pertaining to the surface of the earth or the surficial features formed by geologic processes. (Modified from Gary et al. 1972.)

Groundwater: 1) Subsurface water that is in the zone of saturation, as distinct from surface waters, or water in the vadose zone or capillary fringe. 2) More loosely, all subsurface water as distinct from surface water. (Modified from Gary et al. 1972.)

Hardpan: A hardened or cemented soil horizon or layer. The soil may be sandy or clayey and cemented by various mineral substances. See "Soil Survey of San Diego Area, California" (Bowman 1973).

Headwaters Basin: A basin with no surface water-connected basins further upstream; usually with an outlet but no inlet.

Highest Sustainable Functional Capacity: The level of functional capacity achieved across the suite of functions by a wetland under reference standard conditions in a reference domain. This approach assumes that the highest sustainable functional capacity is achieved when a wetland ecosystem and the surrounding landscape are undisturbed.

Hydrogeomorphic Wetland Class: The highest level in the hydrogeomorphic wetland classification system. There are five basic hydrogeomorphic wetland classes including depression, fringe, slope, riverine and flat.

Hydrogeomorphic Unit: Hydrogeomorphic units are areas within a wetland assessment area that are relatively homogenous with respect to ecosystem scale characteristics such as microtopography, soil type, vegetative communities or other factors that influence function. Hydrogeomorphic units may be the result of natural or anthropogenic processes. See Partial Wetland Assessment Area.

Hydrologic Network: A group of pools that is interconnected on the surface and often subsurface as well. Connections are determined by surveying pool groups in the field. Water movement is usually in a dendritic pattern, much like stream systems, but occasionally swales will braid.

Hydroperiod: The annual duration of flooding or ponding (in days per year) at a specific point in a wetland.

Indicator: Indicators are observable characteristics that correspond to identifiable variable conditions in a wetland or the surrounding landscape.

Indirect Measure: A qualitative measure of an assessment model variable that corresponds to an identifiable variable condition.

Indirect Impacts: Impacts resulting from a project that occur concurrently, or at some time in the future, away from the point of direct impact. For example, indirect impacts of a project on wildlife can result from an increase in the level of activity in adjacent, newly developed areas, even though the wetland is not physically altered by direct impacts.

Invasive Species: Generally exotic species without natural controls that out compete native species.

In-kind Mitigation: Mitigation in which lost functional capacity is replaced in a wetland of the same regional wetland subclass.

Invert: The bottom of a channel, pipe or culvert.

Interflow: The lateral movement of water in the unsaturated zone during and immediately after a precipitation event. The water moving as interflow discharges directly into a stream or lake.

Isolated Basin: A basin with neither an inlet nor an outlet.

Jurisdictional Wetland: Areas that meet the soil, vegetation, and hydrologic criteria described in the "Corps of Engineers Wetlands Delineation Manual" (Environmental Laboratory 1987) or its successor.

Landscape: The area surrounding a pool or pool complex. It may or may not be greater than a pool's catchment area. Can be natural, disturbed, developed or some combination. A synonym for "the setting of a pool."

Landslide Basin Origin: Pools with an origin primarily caused by landslide activity, typically in the headscarp depression at the head of a landslide. Such pools can also form along secondary landslides within the failure mass**.** The southernmost Otay pools(San Diego County) and the Chiquita Ridge pools (Orange County) serve as southern California type localities.

Mediterranean Climate: A climate prevalent in areas surrounding the Mediterranean Sea and in four other mid-latitude coastal regions. It is characterized by rains in the winter months followed by a long drought period in the hottest months of the year.

Mitigation: Restoration or creation of a wetland to replace functional capacity that is lost as a result of project impacts.

Mitigation Plan: A plan for replacing lost functional capacity resulting from project impacts.

Mitigation Ratio: The ratio of the FCUs (Functional Capacity Units= FCI x area) lost in a Wetland Assessment Area (WAA) to the FCUs gained in a mitigation wetland.

Mitigation Wetland: A restored or created wetland that serves to replace functional capacity lost as a result of project impacts.

Model Variable: See Assessment Model Variable.

O Horizon: A layer with more than 12 to 18 percent organic carbon (C) by weight or 50 percent by volume. Form of the organic material may be recognizable plant parts (Oi) such as leaves, needles, twigs, moss, etc., partially decomposed plant debris (Oe) or totally decomposed organic material (Oa) such as muck.

Off-site Mitigation: Mitigation that is done at a location physically separated from the site at which the original impacts occurred, possibly in another catchment.

Ombrotrophic: hydrologically isolated environment that receives all its water and nutrients from precipitation.

Organic matter: Plant and animal residue in the soil in various stages of decomposition.

Out-of-kind Mitigation: Mitigation in which lost functional capacity is replaced in a wetlands of a different regional wetland subclass.

Partial Wetland Assessment Area (PWAA): A portion of a WAA that is identified *a priori*, or while applying the assessment procedure, because it is relatively homogeneous, and different from the rest of the WAA with respect to one or more model variables. The difference may occur naturally, or as a result of anthropogenic disturbance. See Hydrogeomorphic Unit.

Pedogenic Basin Origin: Basins or pools in which the restrictive horizon impeding drainage to groundwater is a hardpan or claypan which has developed *in situ* by soil-forming processes acting over periods of geologic significance, commonly many thousands or hundreds of thousands of years. Most southern California pools are pedogenic, with the Redding-soil pools of the Miramar area serving as the type locality.

Perched Water Table: An upper water table separated from a lower one by a dry zone "Soil Survey of San Diego Area, California." (Bowman 1973). Perched water tables usually form above restrictive horizons or restrictive geologic units. They typically have a much more limited extent than a regional water table.

Pool Type: pools are classified based on their age and origin combined with their geography (coastal mesa, inland valley, etc.). See Table 5.2.

Project Alternative(s): Different ways in which a given project can be done. Alternatives may vary in terms of project location, design, method of construction, amount of fill required and others.

Project Area: The area that encompasses all activities related to an ongoing or proposed project.

Project Target: The level of functioning identified for a restoration or creation project. Conditions specified for the functioning are used to judge whether a project reaches the target and is developing toward site capacity.

Red Flag Features: Features of a wetland or the surrounding landscape to which special recognition or protection is assigned on the basis of objective criteria. The recognition or protection may occur at a Federal, State, regional or local level and may be official or unofficial.

Reference Domain: The geographic area from which reference wetlands are selected. A reference domain may or may not include the entire geographic area in which a regional wetland subclass occurs.

Reference Standards: Conditions exhibited by a group of reference wetlands that correspond to the highest level of functional capacity (highest, sustainable level of functioning) across the suite of functions performed by the regional wetland subclass. The highest level of functional capacity is assigned an index value of 1.0 by definition.

Reference Wetlands: Wetland sites that encompass the variability of a regional wetland subclass in a reference domain. Reference wetlands are used to establish the range of conditions for construction and calibration of functional indices and to establish reference standards.

Region: A geographic area that is relatively homogenous with respect to large-scale factors such as climate and geology that may influence how wetlands function.

Regional Wetland Subclass: Wetlands within a region that are similar based on hydrogeomorphic classification factors. There may be more than one regional wetland subclass identified with each hydrogeomorphic wetland class, depending on the diversity of wetlands in a region and assessment objectives.

Restrictive Horizon: A horizon within or just below the soil which restricts the rate of infiltration, and which has developed as a result of soil-forming processes. Most such horizons are claypans or hardpans of various types.

Restrictive Unit: A horizontal or near-horizontal geologic occurrence, which restricts the rate of infiltration, sometimes leading to development of vernal pools. In addition to restrictive horizons, restrictive units can include low-permeability bedrock surfaces (such as in tinajas) or clay-rich deposits, which form in ponds, lakes, embayments or playas.

Site Potential: The highest level of functioning possible, given local constraints of disturbance history, land use or other factors. Site capacity may be equal to or less than levels of functioning established by reference standards for the reference domain, and it may be equal to or less than the functional capacity of a wetland ecosystem.

Soil Mapping Unit Inclusions: Small areas contained within the mapping unit that are not identified in the name of the map unit and are appreciably dissimilar in one or more properties. See “Soil Survey Manual” (Soil Survey Division Staff, USDA 1993).

Soil Mapping Unit: A map unit is a collection of areas defined and named the same in terms of their soil components. Each map unit differs in some respect from all others in a survey area and is uniquely identified on a soil map. See "Soil Survey Manual" (Soil Survey Division Staff, USDA 1993).

Soil Permeability: A measure of the ease of water movement in soil. See "Soil Survey Manual" (Soil Survey Division Staff, USDA 1993).

Soil Profile: Soil layers exposed by a vertical cut through the soil. See "Soil Survey Manual" (Soil Survey Division Staff, USDA 1993).

Soil Surface: The soil surface is the top of the mineral soil; or, for soils with an O horizon, the soil surface is the top of the part of the O horizon that is at least slightly decomposed.

Swale: A linear drainage feature lacking a channel (or defined bed and banks) of any kind. Many vernal pools drain to swales, or swales constitute their inlets.

Tectogenic Basin Origin: Basins or pools formed primarily along faults or as a result of geologic subsidence of natural origin. Such basins are often sag ponds or have been impounded by uplifted fault scarps. Tectogenic basins are commonly younger than other types of vernal pools. Ponding is supported by a restrictive units formed by deposition of clays originating from beyond the basin periphery, rather than the restrictive horizons developed in place that sustain many other vernal pools. A classic Southern California type locality is the Tierra Rejada vernal pool in Ventura County.

Terminal Basin: A basin with an inlet (or inlets) but no outlet. It collects moisture from a catchment area.

Throughflow: The lateral movement of water in an unsaturated zone during and immediately after a precipitation event. The water from throughflow seeps out at the base of slopes and then flows across the ground surface as return flow, ultimately reaching a stream or lake. See Interflow for Comparison.

Tinaja: A pool formed as a basin in bedrock, with bedrock being the sole restrictive unit.

Type Locality: The place where a geologic or geomorphic feature is most evidently developed, frequently the locality where it was first described and recognized. (Modified from Gary *et al*. 1972.)

Uplands: Two distinct uses. 1) The area surrounding a pool, basin or other hydrologic feature lacking sufficient wetland indicators to be classified as a wetland. 2) The high ground surrounding a water-collecting feature in which water does not flow on surface or is not detained at the surface. (Modified from Gary *et al*. 1972.)

Variable: An attribute or characteristic of a wetland ecosystem or the surrounding landscape that influences the capacity of a wetland to perform a function.

Variable Condition: The condition of a variable as determined through quantitative or qualitative measures.

Variable Index: A measure of how an assessment model variable in a wetland compares to the reference standards of a regional wetland subclass in a reference domain.

Water table: The highest part of the soil or underlying rock material that is wholly saturated with water. See "Soil Survey of San Diego Area, California" (Bowman 1973).

Watershed: See Catchment Area.

Wetland Ecosystem: "Areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." (Corps Regulations 33 CFR 328.3 and EPA Regulations 40 CFR 230.3). In a more general sense, wetland ecosystems are three-dimensional segments of the natural world where the presence of water, at or near the surface, creates conditions leading to the development of redoximorphic soil conditions, and the presence of a flora and fauna adapted to the permanently or periodically flooded or saturated conditions.

Wetland Assessment Area (WAA): The wetland area to which results of an assessment are applied.

Wetland Banking: The process of establishing a 'bank' of created, enhanced, or restored wetlands to serve at a future date as mitigation of project impacts.

Wetland Creation: The process of creating a wetland in a location where a wetland did not previously exist.

Wetland Enhancement: The process of increasing the capacity of a wetland to perform one or more functions. Wetland enhancement can increase functional capacity to levels greater than the highest sustainable functional capacity achieved under reference standard conditions, but this happens usually at the expense of sustainability or a reduction of functional capacity of other functions.

Wetland Functions: The normal activities or actions that occur in wetlands ecosystems, or simply the things that wetlands do. Wetland functions result directly from the characteristics of a wetland ecosystem and the surrounding landscape, and their interaction.

Wetland Restoration: The process of restoring wetland function in a degraded wetland.

Wetland Periphery: 20-ft band parallel to the basin edge.

Wetland Values: The worth of wetland functions to an individual or society.

Appendix B
Summary of Functions and Variables

Function 1. Surface and Sub-surface Water Storage

Definition

The surface and subsurface water storage function is defined as the capacity of the vernal pool wetlands complex to capture and store precipitation falling on the basin and catchment area. Moisture is stored within the depression as free water on the surface and/or in the surface and subsurface soils of the pool, swale(s) connecting pools and adjacent uplands. Water moves into and out of the basin by defined inlets and outlets and/or to and from the soil of the associated swales and adjacent uplands. It is also lost by evaporation, evapotranspiration, leakage through the sub-surface soil strata and spillage when the basin's storage capacity is exceeded, if an outlet is present. In this guidebook, we only assess free water on the surface of the basins.

Moisture retention and storage depend on a basin soil profile containing one or more restrictive layers that retard drainage. Surface soils in the depression generally have a high clay content. Underlying the surface horizons may be a cemented hardpan (or "duripan"), accumulated clays, bedrock or other poorly permeable layer(s). Ponding occurs when the soils become fully saturated above the restrictive horizon. The depth and texture of the surface soils within the basin, coupled with the permeability of the sub-layers, govern the amount of water required to initiate ponding and also affect the subsequent hydroperiod, plant rooting depth and moisture availability after surface water disappears. Initiation of the first seasonal ponding event may involve processes that differ from those which sustain ponding following mid- or late-season saturation of the pool's watershed.

In addition to water, dissolved solids (salts) move from the pool into the bank and downstream through the outlet. Virtually all vernal pools observe an annual cycle commencing with relatively higher salinities during the initial rains of the season, when ponding mobilizes evaporated salts stored on and in the bed of the pool, or in the bank. A mid-season salinity minimum coincides with rainfall onto the inundated area of the pool and flow from the pool into the adjoining banks. Water flows back into pools from adjacent banks as the water table in the surrounding soils rises. Salts are subsequently concentrated by evaporation during seasonal desiccation. Thus, vernal pools store and regulate salts within a given pool complex or network of vernal pools, and modulate the episodic release of salts at the onset of the wet season. Perhaps not surprisingly, some of the plants and animals that typically occupy pools are salt-sensitive.

As with other bodies of water, vernal pools also store and redistribute heat in their narrow niche between the atmosphere and the soils. The life cycles of biota within the pools are often governed by the onset of threshold temperatures early and late in the season.

Quantitative, direct measures for this function include catchment precipitation, water depth, salinity (or dissolved solids, generally measured as specific conductance[1]), water temperature, water table elevations and seasonal hydrographs.

Rationale for Selecting the Function

Surface and subsurface water storage modulates the movement of water in a climate known for highly seasonal, infrequent and often intense storms that generate rapid runoff. Retention of soil moisture beyond the rainy season extends the growing period. Bio-geo-chemical cycling is facilitated in a region where rates of primary productivity and decomposition are limited by aridity. Water, salt and temperature storage provide the necessary conditions for the unique wetland-dependent vernal pool plant and animal communities to develop. Standing water also excludes many species with limited to no inundation tolerance, dictating the nature of biological interactions within the pool. The role of vernal pools in storing and modulating solutes and temperatures also affects habitats further down in the watershed. Together, pools are wetland patches in a matrix of terrestrial, upland vegetation. Even vertebrate and invertebrate animals that do not require standing water of particular salinities utilize the wetland flora and fauna for food, shelter or some portion of their life cycle.

Characteristics and Processes that Influence the Function

<u>Natural Characteristics and Processes</u>

The primary natural influences on the water storage capacity of depressional southern Californian vernal pool wetlands are geomorphology, soil characteristics and the Mediterranean climate. The geomorphic origins of southern California's vernal pools are diverse, ranging from pedogenic to tectogenic to alluvial processes. The origin of the surface on which the pools have

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[1] Specific conductance, electrical conductance and electrical conductivity are terms that are functionally synonymous and may be used interchangeably for the purposes of this guidebook. Specific conductance is used preferentially in this document, especially where use of this term can avoid confusion with hydraulic conductivity (permeability).

developed determines the soil series of the landscape that in turn affects the soil characteristics both of the upland catchment areas and the depressions themselves. Although the entire region experiences a Mediterranean climate, distance from the coast, elevation and presence of a rain shadow influence the amount and timing of precipitation, as well as the seasonal temperature regime.

The topography of the landscape affects the size and nature of the catchment area and the volume, directional flow and rate of water movement. Microtopographic features such as pool volume, the presence of inlets and/or outlets and the pool's relative position in a network or chain of pools are important factors determining each pool's unique water storage capacity and hydroperiod. Soil texture and the depth of the various soil layers affect the infiltration rate, the amount of water that can be stored in the soil and the amount and intensity of rain necessary to initiate ponding.

The timing and amount of water movement through vernal pools also regulate the transport of nutrients, organic carbon, sediments and biological propagules. Southern Californian pools on pedogenic or alluviated surfaces occur in a mosaic of hummocks (mounds), swales and depressions—all of similar scale —that direct the capture of precipitation and the flow of water salts, particulates and propagules. Other pools have developed more or less in isolation, and their physical arrangement and connections are less complex.

Regardless of the soil series of the surrounding landscape, the soil profile of pool basins must contain surface and/or sub-surface layers that retard drainage. Generally there is a clayey layer (or layers) 1-2 ft deep, often underlain by an even less permeable claypan, duripan or bedrock layer. The characteristic of the claypan and the presence or absence of the underlying duripan tend to be remarkably similar within a given soil series, even beyond southern California. For example, vernal pools situated in San Diego's Redding soils share many attributes with Central Valley vernal pools in the same soil type. Although the soil profile within pool depressions is universally different than the profile of adjacent uplands, the depression soils have not been formally named or described as a soil series, simply because they are not sufficiently extensive to meet mappable-unit criteria.

The Mediterranean climate is distinguished by a rainy season during the coolest months of the year, followed by a near absence of precipitation during the hottest months. In common with all arid climates, yearly precipitation is unpredictable in amount and within years storm patterns vary. Rainfall interacts with pool landscape position and basin morphology to affect the hydrology of both individual pools and networks of interconnected pools. The intensity, timing within a season and frequency of precipitation events is important to the number, depth and duration of ponding episodes and controls spillage from one basin to another (Bauder 2005, Knudsen *et al.* 1991, Leibowitz and Vining 2003). Because vernal pool wetlands are intermediate between dry, upland ecosystems and permanent bodies of water, even slight changes in pool hydrology can favor species that are not characteristic of vernal pools, possibly leading to major changes in biological interactions.

Mediterranean climates typically display cycles of wet and dry years. Vernal pool fields are almost unique within these landscapes because wet/dry cycle effects are minimal. This is likely due to the limited soil volume of water storage in the typically thin mantle of soils. However, seeds and cysts of some vernal pool species can persist for years or decades awaiting favorable hydrologic conditions. The limitations on water (and on nutrient and salt) storage also highlight how small the annual water storage buffer can be, and (due to the thinness of the soils) the fragility of the pool complexes in many respects.

Human Induced Influences

Human activities affect the capture, movement and storage of water in depressional vernal pool wetlands. Modifications to the uplands, wetland edge or directly to the wetland itself may greatly affect the receipt and retention of water. If catchment areas are augmented or reduced, the altered hydroperiods of individual pools will impact the biogeochemical cycles, the species composition and the phenology, life cycles and population dynamics of individual species residing in both the basins and adjacent uplands. Conversion to urban uses, blading, roads, damming, drains or culverts alter the capture and movement of water. Plowing, disking, grazing, fire and brushing can accelerate erosion of sediments into pools, reducing their volume and altering the soil profile. Soil infiltration rates may be diminished if vegetative cover is reduced or eliminated, or if the populations of burrowing animals that depend upon pools are changed. Alterations to inlets, outlets or pool connections impact the amount and delivery rate of water and the transport of other substances, as well as the persistence of flow into downstream pools and channels, even if the area of the catchment itself remains unchanged. Ripping, disking, blading and other surface and subsurface soil disturbances may alter a pool's ability to pond water by damaging or rearranging the soil layers responsible for water retention. Changes in the soil profile can also affect infiltration rates and soil storage of water within the soils of the basin and the adjacent uplands. Increased inflow can cause channels to form in the swales connecting pools, fundamentally altering their functions. Human induced changes in pool hydrology cause compositional changes to both the plant and animal communities, affect their seasonal development and population dynamics, interfere with the movement of biological propagules and genetic material and impact characteristic biological interactions such as predation, herbivory, competition and pollination.

The Hydrological Definition of a Vernal Pool

Extreme alterations to a vernal pool's hydrology can have a number of consequences. For example, retention and storage may be diminished to the point that the depression is no longer recognizable as a wetland of any type. Alternatively, above-ground water retention may be so augmented that the depression has become a permanent or semi-permanent pond, rather than a vernal pool. Although hydrological function can be viewed in absolute terms (the absolute amount of water storage a depression facilitates), we have instead chosen to define it with reference to the natural characteristics of an undisturbed vernal pool system. Specifically, a particular vernal pool functions at its highest level when it stores water at a level and for a period that is typical for an undisturbed vernal pool with the same landscape position, soil profile and level of connectivity. Thus, increases and decreases in an undisturbed vernal pool's water storage capacity lead to loss of function, and depressions that no longer fit the definition of a vernal pool have no value for this function.

Practically speaking, users of this guidebook should evaluate all depressions in terms of the definition of vernal pools as outlined at the beginning of Chapter 3 and in the "Description of the Regional Wetland Subclass" contained within that chapter. For hydrology, the critical elements of that definition are the pool's primary water source (precipitation), topography (natural depression, with or without inlets and/or outlets), seasonality (water ponds during the annual rainy season) and temporariness (ponds dry out once per annual seasonal cycle).

Functional Capacity Indices: Direct and Indirect

<u>Direct Functional Capacity Index</u>

The Direct FCI can only be calculated if seasonal precipitation exceeds 14 cm (See Appendix D.1).

Model Variables

$V_{TOTPRECIP}$ = Total precipitation (cm) for the rainfall year at Lindbergh Field, San Diego.

$V_{PERCENT\_2MONTHS}$ = percent of total precipitation during the rainfall season that fell during the two months with the highest rainfall amounts. Expressed as a whole number between 0 and 100.

$V_{POOLCONNECT}$ = indicator variable that characterizes surface connection of the pool to other pools. 1= none/isolated, 2= headwaters (outlet only), 3= flow through (inlet and outlet), 4=terminal/collector (inlet only)

$V_{TOTINUND}$ = total number of days during the rainy season the pool was inundated, at the lowest elevation.

$V_{PONDING\_EVENTS}$ = number of times the pool was inundated during the rainy season, at the lowest elevation.

$V_{MAXINUNDEPTH}$ = maximum depth of inundation during the season, in cm.

$V_{SC\_TOTINUND}$, $V_{SC\_PONDING\_EVENTS}$, $V_{SC\_MAXINUNDEPTH}$ are scaled versions of the previous three variables, based on $V_{POOLCONNECT}$ and $V_{TOTPRECIP}$ as follows:

Dry years: $14.0 \leq V_{TOTPRECIP} \leq 17.5$ cm
OR ($17.5 \leq V_{TOTPRECIP} \leq 25.0$ cm and $V_{PERCENT\_2MONTHS} < 50$)

$V_{TOTINUND}$			0	1-29	30-50	51+
$V_{SC\_TOTINUND}$			0.5	1	0.5	0.1

$V_{PONDING\_EVENTS}$			0	1-3	4-6	7+
$V_{SC\_PONDING\_EVENTS}$			0.5	1	0.5	0.1

$V_{MAXINUNDEPTH}$			0	0.1-11.0	11.1-40.0	40.1+
$V_{SC\_MAXINUNDEPTH}$			0.5	1	0.5	0.1

Average to Above Average years: $25.1 \leq V_{TOTPRECIP} \leq 32.0$ cm
OR ($17.5 < V_{TOTPRECIP} < 25.0$ cm and $V_{PERCENT\_2MONTHS} \geq 50$)

$V_{TOTINUND}$		0	1-16	17-54	55-140	141+
$V_{SC\_TOTINUND}$		0.25	0.5	1	0.5	0.1

$V_{PONDING\_EVENTS}$		0		1-4	5-8	9+
$V_{SC\_PONDING\_EVENTS}$		0.25		1	0.5	0.1

$V_{MAXINUNDEPTH}$		0	0.1-1	1.1-24.0	24.1-50.0	50.1+
$V_{SC\_MAXINUNDEPTH}$		0.25	0.5	1	0.5	0.1

Wet years: 32.1 ≤ $V_{TOTPRECIP}$						
$V_{TOTINUND}$	0	1-7	8-27	28-108	109-172	173+
$V_{SC\_TOTINUND}$	0	0.25	0.5	1	0.5	0.1
$V_{PONDING\_EVENTS}$	0		1	2-7	8-10	11+
$V_{SC\_PONDING\_EVENTS}$	0		0.5	1	0.5	0.1
$V_{MAXINUNDEPTH}$	0	0.1-4.0	4.1-11.9	12.0-31.0	31.1-50.0	50.1+
$V_{SC\_MAXINUNDEPTH}$	0	0.25	0.5	1	0.5	0.1

Index of Function

The Direct FCI depends on landscape position ($V_{POOLCONNECT}$) as follows:

If ($V_{POOLCONNECT} = 1$)

Direct FCI= ($0.62 \times V_{SC\_PONDING\_EVENTS}$) + ($0.38 \times V_{SC\_MAXINUNDEPTH}$)

If ($V_{POOLCONNECT} = 2$)

Direct FCI= ($0.31 \times V_{SC\_TOTINUND}$) + ($0.64 \times V_{SC\_PONDING\_EVENTS}$) + ($0.05 \times V_{SC\_MAXINUNDEPTH}$)

If ($V_{POOLCONNECT} = 3$)

Direct FCI= ($0.15 \times V_{SC\_TOTINUND}$) + ($0.20 \times V_{SC\_PONDING\_EVENTS}$) + ($0.65 \times V_{SC\_MAXINUNDEPTH}$)

If ($V_{POOLCONNECT} = 4$)

Direct FCI= ($0.40 \times V_{SC\_PONDING\_EVENTS}$) + ($0.60 \times V_{SC\_MAXINUNDEPTH}$)

The degree to which a basin provides water storage is a complex function of its depth, length of ponding, and the number of ponding events, calibrated to its particular landscape position (*e.g.,* headwaters vs. terminal pool), and patterns of rainfall in any particular year. Each of the three primary variables for this function ($V_{TOTINUND}$, $V_{PONDING\_EVENTS}$ and $V_{MAXINUNDEPTH}$) is scaled based on precipitation patterns, with a greater amount of water retention expected in years with more rainfall. As seen in the table above, maximum values of 1.0 are obtained for intermediate levels of $V_{SC\_TOTINUND}$, $V_{SC\_PONDING\_EVENTS}$ and $V_{SC\_MAXINUNDEPTH}$ that are characteristic of reference standards. Greater amounts of rainfall facilitate greater discrimination of pool function. For example, each of the three primary variables is scaled based on only 3 bins for low rainfall years, and 5-6 bins for high rainfall years.

The three primary variables correlate to differing degrees with the direct FCI, depending on their landscape position. The total length of inundation does not predict function in isolated pools and terminal pools ($V_{POOLCONNECT}$ = 1, 4), but it is an important variable for headwater and flow through pools ($V_{POOLCONNECT}$ = 2, 3). Similarly, the number of ponding events is the most important variable for isolated and headwater pools, but the maximum inundation depth is more relevant for flow through and terminal pools.

Indirect Functional Capacity Index

Model Variables

$V_{COBBLESBA}$ = 100 X (percent of the basin covered with rounded or angular coarse pebbles or cobbles). Pebbles are 2-7.5 cm in diameter and cobbles are 7.5-25 cm in diameter (Soil Survey Manual, USDA 1993).

$V_{COBBLESBA>15}$ = indicator variable: 0 if $V_{COBBLESBA} \leq 15$,
1 if $V_{COBBLESBA} > 15$.

$V_{MAXDEPTH}$ = maximum depth of the pool in meters, as estimated with surveying equipment.

$V_{MAXDEPTH\_GR}$ = categorical groups for maximum depth of the pool:

$V_{MAXDEPTH\_GR} = 0.32$ if $V_{MAXDEPTH} \leq 0.11$ m

$V_{MAXDEPTH\_GR} = 0.37$ if 0.11 m $< V_{MAXDEPTH} \leq 0.35$ m

$V_{MAXDEPTH\_GR} = 0.00$ if 0.35 m $< V_{MAXDEPTH}$

$V_{DIST1km<5}$ = indicator variable for whether disturbance in the four 1km quadrants is less than Category 5 in all cases: 0 if Dist1km-1 > 4, Dist1km-2 > 4, Dist1km-3 > 4 and/or Dist1km-4 > 4; 1 if Dist1km-1 < 5, Dist1km-2 < 5, Dist1km-3 < 5 and Dist1km-4 all less than 5. (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories.

$V_{POOLCONNECT}$ = indicator variable that characterizes surface connection of the pool to other pools. 1= none/isolated, 2= headwaters (outlet only), 3= flow through (inlet and outlet), 4=terminal/ collector (inlet only).

$V_{DEFIN\_OR\_OUTLET}$ = 1 if pool has a defined inlet or defined outlet, 0 otherwise.

V_{LENGTH} = length of longest axis (a) in meters, using the basin edge as determined in the field.

V_{SLOPE} = Long axis slope= $V_{MAXDEPTH} / (V_{LENGTH} / 2)$.

V_{SLOPE_GR} = categorical groups for slope:

$V_{SLOPE\_GR} = 1$ if $V_{SLOPE} \leq 1.9$

$V_{SLOPE\_GR} = 2$ if $1.9 < V_{SLOPE} \leq 3.0$

$V_{SLOPE\_GR} = 3$ if $V_{SLOPE} > 3.0$

$V_{IN\_OR\_OUTLET\_WS}$ and V_{SLOPE_WS} = variables specific to the water storage function that are calculated based on $V_{POOLCONNECT}$ as follows:

$V_{POOLCONNECT} = 1$			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.05	1	0.15
1	0.00	2	0.15
		3	0.00

$V_{POOLCONNECT} = 2$			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.05	1	0.06
1	0.00	2	0.15
		3	0.00

$V_{POOLCONNECT} = 3$			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.08	1	0.08
1	0.00	2	0.12
		3	0.00

$V_{POOLCONNECT} = 4$			
$V_{DEFIN\_OR\_OUTLET}$	$V_{IN\_OR\_OUTLET\_WS}$	V_{SLOPE_GR}	V_{SLOPE_WS}
0	0.00	1	0.02
1	0.05	2	0.15
		3	0.00

Index of Function

Indirect FCI= $(0.08 \times V_{COBBLESBA>15}) + (0.35 \times V_{DIST1km<5}) + V_{MAXDEPTH\_GR} + V_{IN\_OR\_OUTLET\_WS} + V_{SLOPE\_WS}$

The Indirect FCI indicates that vernal pools with the highest capacity for water storage tend to have cobbles, lie in undisturbed landscapes, and are between 0.11 and 0.35 m deep. In all pools except terminal pools, the presence of a defined inlet or outlet correlates with some loss of function. Moderate slopes between 1.9 and 3.0 are founded in pools with the highest level of function, with more shallow pools tending to retain some level of function.

Function 2. Hydrologic Networks

Definition

Hydrologic networks are the water bodies through which water moves to the local master stream in a vernal pool landscape. The links include pools, the swales or subsurface flowpaths that connect them or the drainages of various types through which flows move into the master stream. Integrated surface/sub-surface water systems are the general rule in California vernal pools (*cf.*, Rains *et al.* 2006, Rains *et al.* 2008) and prairie potholes (Leibowitz and Vining 2003), although subsurface connections between small, surface-isolated wetlands are not well detailed (see Winter and LaBaugh 2003).

Pools with neither inlets nor outlets are hydrologically isolated and self-contained, unless the depression's substrata leak water to the sub-surface water table or are structured so as to facilitate underground water movement (Knudsen *et al*. 1991, Rains *et al.* 2006, Rains *et al.* 2008, Winter and LaBaugh 2003). Underground flow fields are more complex when isolated depressions are separated by ridges or mounds (Winter and LaBaugh 2003). Pools isolated on the surface export soil, organic carbon, nutrients or biological propagules primarily by wind and animal vectors.

Pools with inlets and/or outlets are part of an interconnected hydrologic system that may be primarily dendritic and linear, or more anastomosing and reticulate (*cf.*, Hickson and Hecht 1991). The topography of the catchment directs water to the basins. The intensity, timing within a season and frequency of precipitation events is important to the number, depth and duration of ponding episodes and controls spillage from one basin to another (Bauder 2005, Knudsen *et al.* 1991, Leibowitz and Vining 2003). Pools may spill and recharge differently under different precipitation patterns, depending on the height and location of potential inlets and outlets and position in the network or pool order (Bauder 2005). Groundwater connections also vary in response to short or long term changes in the weather (Rains *et al.* 2008, Winter and LaBaugh 2003) and the extent to which the summer soil cracks intrinsic to many southern California pools have seasonally annealed or closed in response to the first storms of the year (Hecht *et al.* 1998, Weitkamp *et al.* 1996).

Soil surface texture is important to the rate of moisture infiltration, the storage of water and the time it takes for ponding to occur, or if it does occur. The presence and morphology of poorly permeable sub-surface layers affects how water moves through the soil—laterally, vertically or both—and to what degree pools are hydrologically interconnected below ground. Within those pools with deep soil cracks, connections typically change over the course of a season.

Direct, quantitative measures of the movement of water include dissolved constituent concentrations observed over time (Figure 3.6; see also Rains *et al.* 2008), hydrographs of pools in the network (Figure 3.5) and observations on surface flows.

Rationale for Selecting the Function

Water moving through an interconnected system of pools will generally move more slowly and have greater opportunity to infiltrate the soil in and adjacent to the pool basins, swales and channels. Some of the infiltrated water may discharge into the pools and swales (or channels) further downstream. Longer travel times for the water facilitates retention of more moisture in the system for longer periods of time, recharging the ground-water table, perched or not. Longer periods of moisture availability extend the growing season, a significant effect in arid ecosystems with limited and unpredictable precipitation (Bauder 1989, Hecht and Napolitano 1993).

Hydrological interconnections are important for the export and import of nutrients, organic carbon and sediments. Important elements of the food chain such as aquatic invertebrates, algae, fungi, bacteria, plant parts and seeds become mobile when water spills between basins. The movement of sexual or asexual propagules provides the potential for the species composition of pools to change in response to variable or systematically changing conditions (*i.e.*, climate change). Hydrologic connections can also mitigate the genetic drift that can occur in small isolated populations or provide founders for populations that have become locally extinct.

Characteristics and Processes that Influence the Function

Natural Characteristics and Processes

Hydrologic interconnections between pools result from the interplay of catchment and pool topography, climate and soils. The topography of the catchment directs the surface movement of water over the landscape. Along with the soil profile, the shape and depth of individual basins determine the volume of surface water that can be stored, hence the amount required for spillage. Configurations of basin inlets and outlets depend on the location of swales and channels in the landscape, coupled with small differences in elevation along pool margins. The number and area of basins upstream will influence the duration of flows into a networked vernal pool, as well as the duration of ponding. The locations of inlets and outlets may change with the rate and amount of water flowing through the system or with changes in vegetation growth, sediment and debris deposition and related soil development. The catchment area determines the volume of water that enters and moves through pools, with vegetative cover and soil type playing lesser roles.

The regional Mediterranean climate is characterized by scant precipitation concentrated in the coolest months of the year (Bauder 2005). The amount and pattern of rainfall events is unpredictable within rainy seasons and between rainfall years (July 1-June 30). This climatic variability means that connectedness is a function of the rainfall events in a particular rainfall year, and yearly variation is substantial (Bauder 2005).

Human Induced Influences

Changes to the size and topography of the catchment affect the volume of water entering the pools and the rate and direction of flow. Roads act as dams that diminish flow in some areas, and collect and redirect water. Pools deprived of water may lose their hydrologic connection to other pools or be connected more infrequently. They then become artificially isolated and more vulnerable to local extinctions and invasion by plants and animals with different moisture requirements or tolerances. The potential of "rescue" by propagule import from other pools is diminished.

If a culvert or pipe adds water to the system or if grading connects catchments, the increased volume, rate of movement and force of water can cause spillage where there was none, scour channels and basins, alter inlet and outlet elevations, deliver excess sediment and pollutants and flush basins of nutrients and biological propagules such as seeds and cysts. Trenching that breaches the upper several feet (or more) of the claypan or hardpan, although limited in area, can sharply alter flow within the networks, particularly in dry years. Drainage through backfill placed in utility trenches, if not sufficiently baffled, can permanently re-direct inflows to pools or change their hydroperiods. Catchments that have been bladed, brushed or disked will have different infiltration parameters and be more likely to erode. Deep ripping or conversions to hardscape have even more severe impacts on the normal spillage regime of pools and the nature of their hydrological connections. Conversion of any portion of the catchment—or, in some cases, the landscape—to grazing, agriculture, roads or urban uses, alters the amount of water that can be stored and the timing and direction of water moving through the system. Trails (especially equestrian) and vehicle tracks (off-road, motorcycles, trucks, etc.) can act as drains and dewater an area (Bauder 1994).

Functional Capacity Indices: Direct and Indirect

The functional capacity index for hydrologic networks was developed from observations made in three pool networks: two networks (n=4 and n=8 pools) that were bladed and disked or cultivated over 60 years ago, and a nearly undisturbed pool network of 10 pools. All three networks are of pedogenic origin and developed in the Redding soil series. Data collected from these pool networks indicate that the position within a network influences how often a pool will fill and drain (or evaporate). More rainfall is typically required to establish ponding in pools that are higher in the network, while pools that are lower in the network pond earlier and experience more frequent ponding episodes (See Figure 3.5). Therefore, a network of pools represents an array of interacting pool-specific hydrologic regimes in close proximity to each other. Geomorphic and topographic indicators strongly interact with hydrologic variables to dominate pool network functionality. The Direct FCI can only be calculated if seasonal conditions of precipitation amount are met (See Appendix D.1). In this guidebook, the FCIs for Hydrologic Networks are based on surface connections only.

Direct Functional Capacity Index

Model Variables

$V_{NETPONDING}$ = number of pools in the network that continuously pond ≥ 5 days during the rainy season.

$V_{HEADWATERPOND}$ = number of headwater pools that simultaneously hold water at their lowest elevation.

$V_{FILLEDMAX}$ = the number of headwater basins that filled to their maximum depth at least once during the rainy season.

$V_{TOTINUND}$ = total number of days during the rainy season a pool was inundated, at the lowest elevation.

The variables are scaled according to Table 4.1.

Index of Function

$$\text{Direct FCI} = (V_{NETPONDING} + V_{HEADWATERPOND} + (1.5 \times V_{FILLEDMAX}) + (V_{TOTINUND}/2)) / 4$$

Table 4.1. Direct Assessment of the Hydrologic Network Function

Variables*

$V_{NETPONDING}$= Number of pools in the network that continuously pond water ≥ 5 days during the rainy season.

$V_{HEADWATERPOND}$=Number of headwater pools that simultaneously hold water at their lowest elevation.

$V_{FILLEDMAX}$= Number of headwater pools filled to their maximum depth at least once during the rainy season.

$V_{TOTINUND}$= Total number of days during the rainy season a pool was inundated, at the lowest elevation.

$V_{NETPONDING}$

Measurement or condition- $V_{NETPONDING}$	Index
The number of pools in the network continuously ponding ≥5days is ≥ 7.	1
The number of pools in the network continuously ponding ≥5days is 4-6.	0.5
The number of pools in the network continuously ponding ≥5days is 3.	0.4
The number of pools in the network continuously ponding ≥5days is 2.	0.25
Zero or one pool in the network continuously ponds ≥ 5 days.	0

$V_{HEADWATERPOND}$

Measurement or condition- $V_{HEADWATERPOND}$	Index
Three or more headwater pools pond at the same time.	1
Two headwater pools pond at the same time.	0.75
One headwater pool ponds.	0.5
No headwater pools pond.	0.25
No headwater pools pond when >35 cm of rain falls in a 3-month period.	0

$V_{FILLEDMAX}$

Measurement or condition- $V_{FILLEDMAX}$	Index
Three or more headwater pools fill to their maximum depth.	1
Two headwater pools fill to their maximum depth.	0.75
One headwater pool fills to its maximum depth.	0.4
No headwater pools fill to their maximum depth.	0.25
Only the terminal pool fills to its maximum depth.	0

$V_{TOTINUND}$

Measurement or condition- $V_{TOTINUND}$	Index
One or more pools in the network pond for a seasonal total of ≥40≤60 days.	1
One or more pools in the network pond for a seasonal total of ≥30≤40 days.	0.75
One or more pools in the network pond for a seasonal total of ≥15≤30 days.	0.4
One or more pools in the network pond for a seasonal total of ≥0≤15 days.	0.25
No pools in the network pond during the rainy season.	0

$$FCI= (V_{NETPONDING} + V_{HEADWATERPOND} + 1.5 \times (V_{FILLEDMAX}) + (V_{TOTINUND}/2))/4$$

* Scoring of variables is more fully explained on the data forms in Appendix C.

The network functional capacity increases as the number of pools in the network holding water 5 days or more increases, the number of headwater pools simultaneously holding water increases, the number of basins reaching their maximum capacity increases (which favors spillage) and with the total number of days water stands at the lowest elevation within the basins.

Indirect Functional Capacity Index

Model Variables

$V_{NUMPOOLS}$ = number of pools in a network of pools as determined by field surveys.

$V_{DOMIDISTBA\text{-}NET}$ = indicator variable for the dominant disturbance within the basins in a network. (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories.)

$V_{DOMDISPERI\text{-}NET}$ = indicator variable for the dominant disturbance in the 20-ft peripheral band surrounding the basins in a network. (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories.)

$V_{DOMDISCA\text{-}NET}$ = indicator variable for the dominant disturbance in the catchment area of the pool network. (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories.)

$V_{MODIFCAT\text{-}NET}$ = indicator variable for the type of modification made to the catchment area of the pool network. (1= none, 2= draining/diminishment/truncation, 3= addition/augmentation)

$V_{SEDFILLBA\text{-}NET}$ = indicator variable for the observable deposition of sediment or fill in most of the basins in the network as indicated by deltaic deposition patterns or soil discontinuities in texture or color (1= none, 2= <25% of basin surface, 3= ≥25% of basin surface).

$V_{INLETELEV\text{-}NET}$ = indicator variable for the discernible modification to the inlet elevations of the basins in the network. (1= none, 2= raised, 3= lowered, 4= trenched/ditched)

$V_{OUTLETELEV\text{-}NET}$ = indicator variable for the discernible modification to the outlet elevations of the basins in the network. (1= none, 2= raised, 3= lowered, 4= trenched/ditched)

The variables are scaled according to Table 4.2.

Index of Function

$$\text{Indirect FCI} = (V_{NUMPOOLS} + V_{DOMDISTBA\text{-}NET} + V_{DOMDISTPERI\text{-}NET} + (V_{DOMDISTCA\text{-}NET}/2) + (V_{MODIFCAT\text{-}NET}/2) + V_{SEDFILLBA\text{-}NET} + V_{INLETELEV\text{-}NET} + V_{OUTLETELEV\text{-}NET}) / 7$$

Factors that correlate with hydrologic network function are the number of pools in the network (more connections lead to greater between-basin movement of water, nutrients and

Table 4.2. Indirect Assessment of the Hydrologic Network Function

Variables*

$V_{NUMPOOLS}$= Number of pools in a network of pools as determined by surveying.
$V_{DOMDISTBA-NET}$= Dominant disturbance within the basins in a network.
$V_{DOMDISTPERI-NET}$= Dominant disturbance in the 20-ft peripheral band surrounding the basins in a network.
$V_{DOMDISTCA-NET}$= Dominant disturbance in the catchment area of the pool network.
$V_{MODIFCAT-NET}$= Type of modification made to the catchment area of the network.
$V_{SEDFILLBA-NET}$= Observable deposition of sediment or fill in the basins in the network.
$V_{INLETELEV-NET}$= Discernible modification to the inlet elevations of pools in the network.
$V_{OUTLETELEV-NET}$= Discernible modification to the oulet elevations of pools in the network.

$V_{NUMPOOLS}$

Measurement or condition- $V_{NUMPOOLS}$	Index
The number of pools in the network is ≥7.	1
The number of pools in the network is 4-6.	0.5
The number of pools in the network is 3.	0.4
The number of pools in the network is 2.	0.25
The pool is isolated.	0

$V_{DOMDISTBA-NET}$

Measurement or condition- $V_{DOMDISTBA-NET}$	Index
Dominant disturbance in the basins of the network is Category 1 or 2.	1
Dominant disturbance in the basins of the network is Category 3.	0.75
Dominant disturbance in the basins of the network is Category 4.	0.5
Dominant disturbance in the basins of the network is Category 5.	0.25
Dominant disturbance in the basins of the network is Category 6.	0

$V_{DOMDISTPERI-NET}$ and $V_{DOMDISTCA-NET}$

Measurement or condition- $V_{DOMDISTPERI-NET}$ and $V_{DOMDISTCA-NET}$	Index
Use the same scale as the one used for $V_{DOMDISTBA-NET}$	

$V_{MODIFCAT-NET}$

Measurement or condition- $V_{MODIFCAT-NET}$	Index
Catchment area for the pool network has no modifications.	1
Catchment area for the pool network has been added to/augmented by < 15%.	0.8
Catchment area for the pool network has been increased by > 35% but < 50%.	0.5
Catchment area for the pool network has been drained or diminished; truncated by < 15%.	0.5
Catchment area for the pool network has been drained or diminished; truncated by > 25%.	0.25
Catchment area has been drained, diminished or augmented by a net > 50%.	0

(continued)

Table 4.2. Indirect Assessment of the Hydrologic Network Function	
$V_{SEDFILLBA\text{-}NET}$	
Measurement or condition- $V_{SEDFILLBA\text{-}NET}$	**Index**
No observable deposition of sediment or fill in most of the basins in the network.	1
Observable deposition of sediment or fill covers <25% of most basins in the network.	0.5
Observable deposition of sediment or fill covers ≥25% of most basins in the network.	0.25
$V_{INLETELEV\text{-}NET}$ and $V_{OUTLETELEV\text{-}NET}$	
Measurement or condition- $V_{INLETELEV\text{-}NET}$ and $V_{OUTLETELEV\text{-}NET}$	**Index**
The inlets/outlets in most of the basins in the network have no discernible modification.	1
The inlets/outlets in most of the basins in the network have been lowered.	0.5
The inlets/outlets in most of the basins in the network have been raised.	0.3
The inlets/outlets in most of the basins in the network have been lowered and trenches or ditches connect most pools.	0.2
(concluded)	
FCI= $(V_{NUMPOOLS} + V_{DOMDISTBA\text{-}NET} + V_{DOMDISTPERI\text{-}NET} + (V_{DOMDISTCA\text{-}NET}/2) + (V_{MODIFCAT\text{-}NET}/2) + V_{SEDFILLBA\text{-}NET} + V_{INLETELEV\text{-}NET} + V_{OUTLETELEV\text{-}NET})/7$	
* Scoring of variables is more fully explained on the data forms in Appendix C.	

propagules) and the extent of disturbance. This includes disturbance in the basin and surrounding area (periphery, catchment), deposition of sediment or fill and alteration of basin inlets or outlets.

Function 3: Maintain Characteristic Biogeochemical Processes

Definition

Like other wetland ecosystems, vernal pools process and cycle elements (*e.g.*, carbon, nitrogen, phosphorus) that are important to sustaining viable populations and communities in the catchment basin and downstream. The cycling of nutrients and other elements in these small systems is driven in part by the import-export of materials through hydrological transport (Bedford 1996, Jocqué *et al*. 2007, Rains *et al.* 2006, Rains *et al.* 2008) and in part by metabolism of organisms, including anabolic (*e.g.*, primary and secondary production) and catabolic processes (*e.g.*, respiration, decomposition) (Boon 2006, Cronk and Fennessy 2001). Wetlands are well known to have biogeochemical processing rates that exceed those in most terrestrial ecosystems (Mitsch and Gosselink 2000, Schlesinger 1997). Due to the arid climate of the San Diego region, this difference is more pronounced, even though vernal pools may be immersed for only part of a year. Undisturbed San Diego vernal pools are oligotrophic ecosystems, because water inputs in undisturbed pools are largely via rainfall or local interflow among pools, rather than overland flow throughout catchment basins, and because pools are located on ancient, well-leached soils and have relatively brief hydroperiods. Anthropogenic eutrophication, alterations to hydrology (*e.g.*, enhanced overland flow via impermeable surfaces or artificial conveyance structures) and soil disturbances in the basin or its catchment (*e.g.*, earth-moving, alteration of inlets and outlets, etc.) can all alter the typically oligotrophic vernal pool biogeochemical functions.

Rationale for selecting the function

Biogeochemical processes represent an integrative measure of the ecological function of an ecosystem, and so represent an overall measure of ecosystem functional integrity, including the effects of anthropogenic eutrophication, soil disturbances, sediment and chemical runoff, and landscape-scale disturbances. As such, biogeochemical cycling and processing provide a tool to evaluate vernal pool function not provided by other HGM functions that focus on biota or physical variables.

Characteristics and Processes that Influence the Function

Hydrology, soil structure and composition and vegetation are key to biogeochemical processes. Hydrology drives the import and export of materials, as well as the oxidative state of the water and underlying sediment, and thus the selective conditions for vegetative and microbial uptake and processing of materials. Soil structure (or conversely, soil disturbance) is critical because deposition and leaching of materials occur in soils. The long-term development of aerobic/anaerobic interfaces also determines nutrient availability and organic matter processing rates. Soil composition affects the supply of particular minerals, the cation exchange capacity and pH. Vegetation responds to both hydrology and soils, and serves as a major processor of nutrients and organic matter production.

An assessment of biogeochemical function requires integrative analyses over extended time periods. Ideally, this would include variables related to phosphorus and nitrogen flux, and organic matter processing. Direct measures of this function would include estimates of primary productivity for algae and flowering plants, documentation of litter decomposition rates and the presence, concentration and form of various elements and compounds tied to specific processes (*e.g*., denitrification), breakdown of organic compounds and changes in availability of various compounds related to changes in pH and oxidation states. It is clear from the literature that the hydrology, soils and geomorphology of basins and catchments are all strongly related to biogeochemical processes occurring in wetlands. Thus, variables such as seasonal hydrographs, catchment area, network position and basin morphometry might be good candidates for indirect indicators of function.

For this HGM, we had intended to do chemical and textural analysis of soils collected from the adjacent uplands, basin edge and pool bottom. Due to equipment failure in the analytical laboratory, we were not able to use these data. We had also prepared for chemical analysis of water samples collected three times during the rainy season. Unfortunately, San Diego experienced its driest year on record during that particular rainy season, and no basins held water. Vegetative cover data were unusable, due to the extreme drought.

Function 4. Maintain Characteristic Plant Community

Definition

The plant community function is defined as the capacity of the wetland habitat to support persistent populations of plant species characteristic of vernal pools in southern California. These populations consist of actively growing plants; dormant structures such as roots, stems, caudices, corms, and bulbs; and the soil seed bank. Soil type and depth, pool hydrology and catchment topography interact with climate to provide suitable conditions for the growth and reproduction of this plant community known as vernal pool ephemeral (Thorne 1976).

Direct measures of this function include plant surveys, estimates of native plant cover, recovery or germination of propagules from the soil and the collection of multi-year population data for key species. Indirect measures would include indicators of a suitable soil profile and capacity to pond.

Rationale for Selecting the Function

This function is important for the intrinsic value of the plant community, which is dominated by endemic species, many of which have very limited distributions. It is also important to numerous wetland processes such as productivity and biogeochemical cycling as well as providing food and habitat for animal communities.

Characteristics and Processes that Influence the Function

Natural Characteristics and Processes

The primary natural influences on the capacity of depressional southern Californian vernal pool wetlands to support the characteristic plant community are shared by the "Surface and sub-surface water storage" function. These are geomorphology, soil and the Mediterranean climate. Various combinations of geomorphology, soil series and local climatic conditions result in a multiplicity of unique wetland habitats even within the reference domain (Bauder and McMillan 1998). Elevation and distance from the coast cause deviations from the prevailing regional climate. The pattern of local, unique wetland habitats extends along the western coast of North American from Baja California MX to the State of Washington.

The numerous, unique combinations of environmental conditions have promoted endemism, often very narrow. For example, the genus *Pogogyne* has three species in San Diego County and adjacent Baja California MX. Each species is faithful to a different soil type, and there is no indication their distributions ever overlapped (Bauder and McMillan 1998). Other genera sort out according to elevation. There are two species of *Downingia* in San Diego County. One, *Downingia cuspidata*, occurs near the coast and in the inland valleys. The other species, *Downingia concolor* var. *brevior*, is found in the county's montane wetlands where winter temperatures are lower and yearly precipitation is greater.

Geomorphology is important to the delivery and ponding of water in pool basins, hydrologic connections between pools and the relationship of pools to adjacent uplands. Soils buffer moisture losses and gains by storing and releasing water from pool basins and the surrounding uplands. Plants can use soil water during dry periods between rainstorms and long after standing water has disappeared at the end of the rainy season. Soil moisture and ponding water promote the growth of dense stands of herbaceous plants quite different from the vegetation in the catchment or landscape. These plants provide animals with a broader diet for a longer period of time than does the upland plant community. The species are less woody and likely more palatable and nutritious compared to the xerophytes that dominate the area, although this has never been examined.

Plants that regularly occur in southern California's vernal pool wetlands are well adapted to the bi-phasic nature of the habitat (wet and dry) and the high variability in moisture conditions within and between years. Within rainfall years (July 1-June 30), precipitation varies widely in total amount, storm intensity and the distribution of storms across the wet season (Bauder 2005). To persist in this variable and unpredictable environment, both plants and animals must cope with rising and falling water levels during the rainy season, a large among-year variation in the longest continuous period of inundation, rapid changes from terrestrial to aquatic conditions and back again, and long periods of high air and soil temperatures coupled with lack of moisture. Various traits have been associated with persistence in such stressful or fluctuating environments. These include dormant eggs, cysts or seeds (Baskin and Baskin 1989, Salisbury 1970, Venable and Burquez 1989, Williams 1998), production of drought resistant underground structures such as taproots, corms, caudices or bulbs (Bauder 1992, Crawley 1986ab, Harper 1977, Mueller-Dombois and Ellenberg 1974, Sheikh 1978), morphological plasticity (Crawford 1987; Deschamp and Cooke 1983, 1984; Hook 1984; Horton 1992; van der Sman *et al.* 1991) and physiological plasticity (Keeley and Morton 1982, Keeley *et al.* 1983), precise requirements for breaking of dormancy (Griggs 1976; Leck 1989; Salisbury 1970; Toy and Willingham 1996, 1967; van der Walk & Davis 1978), precocious reproduction, *i.e.* an annual life history (Barrett *et al.* 1993), and tolerance of lengthy periods of inundation (Bauder 1987a, Crawford 1989, Hook 1984, Jackson and Drew 1984).

Long-term studies along transects spanning the full range of elevations (hence moisture conditions) in vernal pool basins indicate that individual species occupy different portions of the soil moisture/inundation gradient in a series of overlapping distribution curves (Bauder 2000). Natural changes in pool hydrology due to climatic changes could favor some species in relation to others through the direct impacts of longer or shorter, more or fewer periods of ponding. Indirectly, competitive interactions can be altered by changes in hydrology (Bauder 1987a, 1989).

Human Induced Influences

Human activities affect vernal pool vegetation in numerous ways. Pool hydrology is changed by increases or decreases in the catchment area. The catchment area can be augmented or decreased by grading and development. Culverts and channels often connect the catchment to a wider area, thus increasing the amount of water delivered to the pools. Another source of augmented water supply is runoff from hard surfaces or irrigation. Artificial conveyance structures concentrate water flow, thus increasing the force of water entering the catchment. Berms, roads, channels, brow ditches or pipes frequently deprive pools of their normal amount of water. Most development results in drainage and runoff management that directs water away from the area to storm drains.

Too much water can favor herbaceous wetland perennials such as *Typha* spp. and *Eleocharis* spp. Exotic wetlands grasses like *Agrostis avenacea* and *Polypogon monspeliensis* thrive in wetter conditions. These species produce a dense thatch that inhibits seedling growth and reproduction of native pool species (Bauder 1988, Bauder *et al.* 2002). If pools have less water, upland species, particularly those introduced from Asia, can become dense in pool basins. In the absence of inundation sufficiently long to kill them (about 10 continuous days), they outcompete the small, vernal pool annuals (Bauder 1987a, 1989). Water arriving with great force scours channels and inlets and delivers sediment and debris into the basins. Most of the native pool species are diminutive, and sediment and debris bury seeds, seedlings and plants. Changes in topography interrupt the normal drainage patterns in the catchment and often separate pools from their associated uplands. Isolated pools are no longer part of the original hydrological network that determined both hydrology and input and output of nutrients and propagules. Loss of the hydrological buffering provided by uplands favors wider fluctuations in basin ponding frequency and depth and soil moisture content which in turn lead to population fluctuations of pool species (Bauder 1987b). Overland transport of seeds or genes via pollen is diminished or eliminated when uplands are brushed, bladed, graded, cultivated, grazed or developed. Herbivory can increase or decrease when the natural predator/prey relationships are interrupted by truncation of the natural upland habitat. Rabbit and rodent populations in the absence of natural predators such as coyotes or raptors would likely increase. Heavy grazing promotes thick sheets of algae that smother plants (Bauder 1994), as does turf management of golf courses, parks and schoolyards.

Reduction of the landscape or catchment area also exposes pools to more disturbances, often termed “edge effects.” Urban “edge effects” include irrigation runoff that frequently contains nitrates, petroleum-based products, herbicides and other chemicals toxic or damaging to vernal pool plants and animals. Domestic pets prey upon native birds and mammals that are part of the native plant and animal community (Soule *et al.* 1992). Landscape plants and irrigation can change the insect fauna by augmenting resources for native or introduced species, especially during the annual drought period. Honeybees, an introduced species, are frequently seen in vernal pools, and it is likely they have impacted the native pollinators such as solitary ground-dwelling bees (J. Mills unpub. data, Schiller *et al.* 1998). Introduced ant species are strongly associated with irrigation and an augmented water supply (Bolger 1997, Suarez *et al.* 1998). Horse, foot, bicycle and vehicle traffic crushes plants, removes soil and creates channels that can dewater an area (Bauder 1994). Dumping of furniture, appliances, construction debris and other forms of trash impacts pools by covering the soil surface and interrupting drainage patterns (Bauder 1986, 1987b; Bauder *et al.* 1998).

Functional Capacity Indices: Direct and Indirect

The direct functional capacity index for maintenance of characteristic plant communities was developed from floral surveys in the basin and adjacent uplands (periphery) of vernal pools in southern California. From these data, both direct and indirect functional capacity indices were created. Because the direct index estimates the function with more precision, it should be used whenever possible, using the protocol described in Chapter 5 and forms in Appendix C. Personnel with taxonomic training specific for southern Californian vernal pools will be required, and the pools will need to be surveyed in at least two separate years with average or above average precipitation (see Table 5.4 and Appendix D.1). The direct index may be estimated in either the wet or dry phase. If the standing water is too deep or if the dry phase follows a year of below average precipitation, the direct index cannot be successfully estimated.

An indirect functional capacity index is also included, although the information it provides is limited. Because function in the plant community can only be assessed accurately through actual examination of the species that are present, the indirect functional capacity index is considered to be only an approximation.

Plant distribution categories are described more fully in Table 5.6 and descriptions of disturbance categories can be found in Table 5.5 and Appendix D.2.

<u>Direct Functional Capacity Index</u>

Model Variables

V_{BA}= total number of plant species in the basin

$V_{BADI\ 1>0}$ = indicator variable for the presence of any species from distribution category 1 in the pool basin. (0 = none, 1 = one or more species present). Category 1 includes 5 vernal pool species that are state or federally listed as endangered, threatened or rare. (See Table 5.6).

$V_{PERIDI\ 12345}$= total number of plant species from distribution categories 1, 2, 3, 4 and 5 that are found in the uplands (20-ft. peripheral band). This includes all species that are not introduced and excludes upland species that are found in the pool basin (Category 6).

$V_{DI\ 2>0}$= indicator variable for the presence of any species from distribution category 2 in the pool basin or uplands. (0 = none, 1 = one or more species present). Category 2 includes 5 basin species and 27 upland species that are narrowly endemic to southern California. If a typical upland species is found in the basin, it is placed in distribution Category 6 rather than Category 2.

$V_{DI\ 67>17}$ = indicator variable for whether there are more than 17 species from distribution Categories 6 and 7 in the pool basin and uplands (0 = 17 or fewer species, 1 = 18 or more species). If a non-introduced species that is typically found in the uplands (20-ft. peripheral band) is instead found in the basin, it is placed in Category 6. Category 7 consists of 66 species known to be introduced to the reference domain.

Index of Function

Direct FCI = $(0.02 \times V_{BA}) + (0.19 \times V_{BADI\ 1>0}) + (0.01 \times V_{PERIDI\ 12345}) +$
$(0.13 \times V_{DI\ 2>0}) - (0.23 \times V_{DI\ 67>17})$

The characteristic plant community function is enhanced by the presence of listed species and other natives, especially those with restricted distributions. The function is diminished by the presence of species out of place, *i.e.*, upland plants in the basin, or species introduced into the region. Because upland plants are usually intolerant of inundation, their presence in the basin indicates the absence of standing water in the current season and a less hospitable environment for temporary wetlands endemics.

<u>Indirect Functional Capacity Index</u>

Model Variables

$V_{DIST1km<6}$= indicator variable for whether disturbance in the four 1km quadrants is less than Category 6 in all cases. (0 = Dist1km-1, Dist1km-2, Dist1km-3 and/or Dist1km-4 equal to 6; 1= Dist1km-1, Dist1km-2, Dist1km-3 and Dist1km-4 all less than 6).). (See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2 for disturbance categories).

$V_{DOMDISTPERI\_VEG}$= indicator variable for the dominant disturbance in the 20-ft. peripheral band, recoded for the vegetation function.

(1 = $V_{DOMDISTPERI} < 3$;
0 = $V_{DOMDISTPERI} = 3$;
-1 = $V_{DOMDISTPERI} > 3$).

$V_{DOMDISTBA=1}$= indicator for whether the basin is undisturbed per the 6 disturbance categories.

(0 = Domdistba greater than one, 1 = Domdistba equal to one).

$V_{MAXDEPTH<0.36}$= indicator variable for whether $V_{MAXDEP} < 0.36$ m.

(0 = V_{MAXDEP} greater than or equal to 0.36 m,
1 = V_{MAXDEP} less than 0.36 m).

Index of Function

Indirect FCI = $0.2 + (0.2 \times V_{DIST1km<6}) + (0.2 \times V_{DOMDISTPERI\_VEG}) +$
$(0.2 \times V_{DOMDISTBA=1}) + (0.2 \times V_{MAXDEPTH<0.36})$

The characteristic plant community function is diminished by substantial to severe disturbance in the landscape (within a circle of 1 km radius centered on the pool basin), the basin periphery (20-ft. peripheral band) and the basin itself. Basins that are too deep do not support endemic vernal pool flora because these species have limited tolerance for deep water that stands for long periods of time.

Function 5: Maintain Characteristic Faunal Community

Definition

Ephemeral pools provide habitat for a diverse faunal community adapted to the bi-phasic nature of the resource. The faunal community function refers to the capacity of the vernal pool to provide food, cover, and reproductive opportunities for animal taxa for which these wetlands are essential for some or all parts of their life cycle.

Two estimates of the faunal community function are provided: a direct measure based on crustacean community composition, and an indirect measure based on hydrogeomorphic surrogates. Because no single species or suite of species is a reliable indicator for a functional vernal pool, the direct measure of faunal support is specifically calibrated for a subset of pools found in the HGM reference domain.

The indirect version of the model has been calibrated with crustacean community data from the same subset of pools used for the direct model. Further validation could potentially be provided through expanded faunal surveys that include non-crustacean aquatic invertebrates, aquatic and semiaquatic vertebrates, and terrestrial vertebrates and invertebrates that use vernal pools. Because vernal pool inundation patterns are highly variable depending on the timing and amount of precipitation, additional samples from a greater number of inundation events could also be used to refine model calibration. These data sets can be analyzed with general linear models to derive the best indirect functional capacity index. For each non-Boolean HGM variable, scatterplots or boxplots should be examined for potential threshold effects; as such effects are present in the indirect functional capacity indices described below. Details regarding statistical model development are provided in Chapters 2 and 5 of this HGM guidebook.

Rationale for Selecting the Function

Vernal pools provide habitat that is used by a wide variety of animals throughout their life cycle. Vernal pools that have a high degree of faunal functionality maintain this characteristic set of species. In addition to the opportunities for food and reproduction provided by the pool itself (during either the wet or dry phase), connectivity among pools at the landscape level may also be important for some species. This is because 1) their life cycle requires access to both ephemeral pools and other habitat types, or 2) the ecological and evolutionary consequences of dispersal and gene flow among pools in a complex are essential for persistence in individual pools. The second set of processes may be addressed in terms of metapopulation processes, source sink dynamics or maintenance of genetic diversity, depending on the context. Spatial linkages among vernal pools and adjacent habitats within the surrounding landscape facilitate the long-term persistence of a diversity of habitats and characteristic vernal pool plant and animal communities (Ebert and Balko 1987, Holland 1976, Holland and Jain 1981, Hanski 1996, Hansson *et al.* 1995, Simovich, 1998, Thorp and Leong 1998).

The maintenance of characteristic assemblages of invertebrates and vertebrates are typically included in draft models for depressional wetlands, including vernal pools. However, thus far, there has been little success in developing a rapid assessment technique to directly estimate this function. This is due to the taxonomic complexity and variability of animals within and among vernal pools. Vertebrates and terrestrial invertebrates that utilize vernal pools do not easily lend themselves to functional assessment, due to difficulty in accurate field assessments and/or few previous studies. Consequently, this HGM assesses faunal function for vernal pool crustaceans as a surrogate for the entire fauna. Crustaceans are the most numerically important invertebrate faunal group, and include two federally endangered species.

Broad Faunal Categories

Vernal Pool Obligates: These are organisms whose entire life cycle is completed within the pool. The most obvious examples are crustaceans, but this group also includes, nematodes, rotifers and other taxa. The life cycle of obligates is precisely tied to the pools, and these species typically persist through the dry phase as dormant propagules in the pool sediments. Dormant propagules (typically encysted eggs or embryos) hatch when the pools fill, and the organisms quickly mature and reproduce before the pool dries. Some are generalists found in pools that span a variety of abiotic conditions. However, most exhibit limited tolerance ranges for water temperature, chemistry (pH, salinity, alkalinity, turbidity, etc.) and pool duration (due to minimum developmental times). As a result, most vernal pool obligates are narrow endemics found only in a limited geographic area. These organisms feed on those lower in the food chain including algae, bacteria, smaller animals and detritus. They are in turn fed upon by amphibian larva and migratory waterfowl. Dispersal among pools and pool complexes is often mediated by vectors such as birds and mammals. Thus, gene flow, recolonization and potential rescue of pools with low density are all dependent upon maintenance of appropriate vectors.

Vernal pools in the reference domain contain at least three species of fairy shrimp: the San Diego fairy shrimp *Branchinecta sandiegonensis*, Lindahl's fairy shrimp (also known as the versatile fairy shrimp) *B. lindahli* and the Riverside fairy shrimp *Streptocephalus woottoni*. The San Diego fairy shrimp and the Riverside fairy shrimp are federally endangered species; so appropriate USFWS permitting issues must be addressed before sampling pools in which these species may be present. The distributional patterns of the two *Branchinecta* species have been characterized well enough that their presence figures prominently into the Functional Capacity Index. *B. sandiegonensis* is commonly found in vernal pools with high function. However, within the reference domain for this HGM guidebook, *B. lindahli* tends to occur only in disturbed pools. *S. woottoni* is relatively rare in the HGM reference domain, and was not present in pools that were used to calibrate this function. As a result, this species is not used as a specific indicator of function despite its endangered status. If encountered during sampling, it should be treated like any other crustacean species when calculating $V_{CRUSTSPP}$.

Lifestyle Dependent Organisms: These are organisms that spend only a part of their life cycle in the pools or are dependent on other pool organisms at a certain stage. The most obvious in this group are the amphibians. While some species such as tree frogs can breed in intermittent streams as well, spadefoot toads are in large part dependent on predator-free ephemeral pools. The adults spend the dry season under the ground or in the uplands, rather than the pools. Spadefoots take advantage of rodent burrows to help them get up to a meter deep in the ground. Although tree frogs may exhibit an extended period of activity in the wet season, spadefoots are more precisely adapted to the pool cycle. After emerging during heavy rains (thought to be cued by the sound) they quickly move to pools and breed in one or a very few nights. The adults then return to shallow burrows in the uplands and emerge at night to feed for a short period of time. Tadpoles develop quickly eating pool vegetation, and even more quickly if fairy shrimp are available as prey. Upon metamorphosis, they too return to the uplands.

A large variety of insects also utilize vernal pools, generally for the development of their larval stage. Terrestrial (aerial) insect adults come to the pools to deposit eggs. Many insect larvae are predators on other vernal pool animals. Most vernal pool insects with aquatic larvae will also utilize other water sources, and are thus not totally reliant on ephemeral pools. However, some insect pollinators are obligately dependent on vernal pool plants, with which they have co-evolved specific pollination syndromes.

Opportunists: These are organisms that will take advantage of pools when available. Included are some insects and migratory waterfowl (which may have been more dependent on these pools in the past when they were more abundant). These use the pools as resting and feeding stations (Baker *et al.* 1992). Some species breed around pools. Mammals will also use pools for water sources, and garter snakes feed on tadpoles when available.

Characteristics and Processes that Influence the Function

Natural Characteristics and Processes

In general, it is widely recognized that vernal pools support a unique assemblage of fauna due to the timing and duration of inundation phases; these are in turn dictated by climate, soil characteristics, hydrology and the microtopography of the pool basin (*e.g.*, Bauder *et al.* 1998, Hanes and Stromberg 1998, Keeley and Zedler 1998, Smith and Verrill 1998, Sutter and Francisco 1998). Although vernal pools are sometimes thought of as isolated "bathtubs" driven solely by precipitation and evaporation, they are often linked hydrologically to the remainder of the landscape by groundwater flow through perched aquifers (Rains *et al.* 2006). General descriptions of the origin of southern California's vernal pools, their hydrogeology (water sources and hydrodynamics) soil characteristics and hydrologic variability are found in Chapter 3.

As in many other areas, both rainfall patterns and vernal pool inundation patterns are highly variable in southern California (*e.g.*, Bauder 2005). For animals such as crustaceans that live in these temporary habitats, the fraction of cysts that hatch has evolved to match environmental predictability. To persist in a pond that does not always remain full long enough for maturation and mating, < 100% of cysts hatch during any particular hydration. This phenomenon has been very well studied theoretically and empirically (*e.g.*, Brendonck 1996, Philippi *et al.* 2001, Brendonck and De Meester 2003, Brock *et al.* 2003). For example, in the San Diego fairy shrimp, only 6% of *B. sandiegonensis* cysts hatch during laboratory hydrations (Simovich and Hathaway 1997), and the average pool containing *B. sandiegonensis* fills long enough to allow reproduction approximately once in every three inundation events (Philippi *et al.* 2001).

No single species or taxonomic group is diagnostic for a functional vernal pool. For example, considerable regulatory effort has focused on the San Diego fairy shrimp due to its status as an endangered species, but it is not found in highly functional pools with short inundation times. Thus, an assessment of vernal pool functionality with regards to fauna requires an accurate survey of community composition across the full range of hydroperiods within the geographic and hydrologic domain of the HGM.

Human Induced influences

As described in Chapter 3, human modifications to the uplands, wetland edge or the wetland itself can affect the receipt and retention of water, and thus inundation patterns. Plant and animal communities characteristic of undisturbed vernal pools are generally not present in pools with altered hydrology, and individual species are restricted to pools with particular inundation periods (*e.g.*, Helm 1998, Platenkamp 1998, Simovich 1998, Bauder 2000). For example, disturbed pools tend to facilitate populations of mosquitoes, which are rare or absent in undisturbed pools (*e.g.*, Rogers 1998). In general, many vernal pool crustaceans that are characterized as obligates seem to be more tolerant of human-influenced hydrologic changes than obligate vernal pool plants.

Functional Capacity Indices: Direct and Indirect

The functional capacity index for faunal support focuses on the crustacean community as a surrogate for all vernal pool fauna. We present both a direct and an indirect functional capacity index. The direct index must be based on samples from the wet season, using protocol described in Chapter 5 and Appendix B, and taxonomic identification by personnel with freshwater crustacean training. Such training, for example, would exceed that required for identifying fairy shrimp, as fairy shrimp constitute only one component of the crustacean fauna in a vernal pool.

An indirect functional capacity index is also included, although the information it provides is limited. Thus, the indirect functional capacity index should be considered to be only an approximation. Faunal function can only be assessed accurately through actual collection and analysis of the species that are present. However, if function needs to be assessed when the pool is not holding water, only indirect assessment is possible.

<u>Direct Functional Capacity Index</u>

Model Variables

$V_{MAXDEPTH}$ = maximum depth of the pool in meters, as estimated with surveying equipment.

$V_{CRUSTSPP}$ = total number of crustacean species present.

$V_{FAUNIND}$ = proportion of all crustacean species present that are found in the following list of 14, which are termed "Faunal Indicators":

Cladocera (water fleas): *Alona cf diaphana*, *Ceriodaphnia dubia*, *Macrothrix hirsuticornis*, *Moina micrura*, *Scapholeberis ramneri*, *Simocephalus* sp.

Copepoda (copepods): *Hesperodiaptomus franciscanus*

Ostracoda (ostracods, seed shrimp): *Cypridopsis*, *Cypris pubera*, *Eucypris virens*, *Eucypris* sp., *Herpetocypris*, *Limnocythere*, *Strandesia* sp.

V_{SDFS} = indicator variable for the San Diego fairy shrimp *Branchinecta sandiegonensis*: 0 if absent, 1 if present.

V_{LFS} = indicator variable for the fairy shrimp *Branchinecta lindahli*: 0 if absent, 1 if present.

Dependence on $V_{MAXDEPTH}$

The faunal index can only be estimated directly if $V_{MAXDEPTH} \geq 0.07$ m. There is currently no data set that can be used to describe the characteristic fauna of very shallow pools. Moderately shallow pools, defined as (0.07 m $\leq V_{MAXDEPTH} < 0.15$ m), support fewer crustacean species than deep pools, defined as ($V_{MAXDEPTH} \geq 0.15$ m). This is accounted for in the first row of the functional capacity index below.

Index of Function

The direct faunal index is inferred by evaluating against the most restrictive conditions (where the index = 1.0). If these conditions are not met, move down through successive rows until all index conditions in the row are met.

Generic functional definition	**Index conditions**	**Index**
Pool is functioning at its optimum level and will do so for the foreseeable future.	{ ($V_{CRUSTSPP} > 10$) and ($V_{FAUNIND} \geq 0.6$) and ($V_{SDFS} = 1$) and ($V_{LFS} = 0$) } <u>or</u> { ($V_{MAXDEPTH} < 0.15$) and ($V_{SDFS} = 1$) and ($V_{LFS} = 0$) }	1.0
Pool is functioning at its highest level but is declining, or is functioning at near-optimal levels and will do so for the foreseeable future.	($V_{FAUNIND} \geq 0.5$) and ($V_{SDFS} = 1$) and ($V_{LFS} = 0$)	0.75
Pool has high functionality, is declining, but is recoverable. Alternatively, the pool retains some functionality, is stable or improving, and is recoverable with moderate external effort.	[{ ($V_{FAUNIND} \geq 0.5$) or ($V_{SDFS} = 1$) } and ($V_{LFS} = 0$)]	0.65
Pool retains some function, but is declining and not recoverable. Alternatively, pool has low function but has the potential for self-recovery or restoration.	($V_{FAUNIND} > 0.0$)	0.25
Pool has low function and probably incapable of recovery.	($V_{CRUSTSPP} > 0$)	0.1
Pool retains no functionality.	($V_{CRUSTSPP} = 0$)	0.0

Indirect Functional Capacity Index

Model Variables

$V_{INLETMOD}$ = Indicator variable for discernible modification to inlet: 0= no, 1= raised, 2= lowered.

$V_{MOUNDPRES}$ =Indicator variable for mounds present: 0= no, 1= yes.

$V_{SURFCRACKS}$ = Indicator variable for surface cracks 0= no, 1= shallow, 2= deep (deep=>1 cm wide & 1 dm deep).

Log ($V_{CATCHAREA}$)= logarithm, base 10, of the catchment area (est.) in acres.

Log ($V_{MAXDEPTH}$)= logarithm, base 10, of maximum depth of the pool in meters, as estimated with surveying equipment.

$V_{COBBLESBA}$ = 100 X (percent of basin covered with rounded or angular coarse pebbles or cobbles). Pebbles are 2-7.5 cm in diameter and cobbles are 7.5-25 cm in diameter (Soil Survey Manual, USDA 1993).

Dependence on $V_{MAXDEPTH}$

The faunal index can only be estimated indirectly if $V_{MAXDEPTH} \geq 0.07$ m. There is currently no data set that can be used to calibrate an indirect function for the characteristic fauna of very shallow pools. Moderately shallow pools, defined as ($0.07 \text{ m} \leq V_{MAXDEPTH} < 0.15$ m), differ from deep pools, defined as ($V_{MAXDEPTH} \geq 0.15$ m), in terms of crustacean communities and hydrogeomorphic variables. Accordingly, separate indirect functional capacity indices are presented for moderately shallow and deep pools.

Index of Function for Moderately Shallow Pools

If ($0.07 \text{ m} \leq V_{MAXDEPTH} < 0.15$ m), the indirect faunal index is calculated as:

$$\text{Indirect FCI} = 0.40 + (0.50 \text{ x } (V_{INLETMOD} = 0)) + (0.33 \text{ x Log } (V_{CATCHAREA})) + (0.20 \text{ x } (V_{COBBLESBA} > 10))$$

Note that ($V_{COBBLESBA} > 10$) is a Boolean expression, receiving a value of 1 for ($V_{COBBLESBA} > 10$) and a value of 0 otherwise.

If ($V_{MAXDEPTH} \geq 0.15$ m), the indirect faunal index is calculated as:

$$\text{Indirect FCI} = 0.40 + (0.3 \text{ x } (V_{INLETMOD} = 0)) + (0.20 \text{ x } V_{MOUNDPRES}) + (0.20 \text{ x } (V_{SURFCRACKS} > 1)) + (0.15 \text{ x Log } (V_{CATCHAREA})) + (0.75 \text{ x Log } (V_{MAXDEPTH}))$$

Note that ($V_{INLETMOD}$ = 0) and ($V_{SURFCRACKS}$ > 1) are both Boolean expressions, receiving a value of 1 if the expression is true, and a value of 0 otherwise.

The Indirect FCI reflects the fact that vernal pools with a characteristic crustacean community tend to have large catchment areas in landscapes where mounds are present. Modifications to the pool inlet disrupt hydrologic cycles, negatively impacting crustaceans. Within the basin, features such as cobbles (in shallow pools) and surface cracks (in deeper pools) are also indicative of low disturbance and characteristic hydrologic cycles. For basins deeper than 0.15 m, increases in maximum depth do correlate to some extent with higher crustacean community function.

Appendix B Variable Table

Direct Assessment Variables

Variable symbol	Variable definition	Function(s) used
$V_{TOTINUND}$	total number of days during the rainy season a pool was inundated, at the lowest elevation.	1,2
$V_{TOTPRECIP}$	total precipitaion (cm) for the rainfall year at Lindbergh Field, San Diego.	1
$V_{PONDING\ EVENTS}$	number of times the pool was inundated during the rainy season, at the lowest elevation.	1
$V_{SC\_(\ \ )}$	scaled versions of $V_{TOTINUND}$, $V_{PONDING\ EVENTS}$ and $V_{MAXINUNDEPTH}$ based on $V_{POOLCONNECT}$ and $V_{TOTPRECIP}$.	1
$V_{PERCENT\text{-}2MONTHS}$	percent of total precipitation during the rainfall season that fell during the two months with the highest rainfall amounts. Expressed as a whole number between 0 and 100.	1
$V_{MAXINUNDEPTH}$	maximum depth of inundation during the season, in cm.	1
$V_{NETPONDING}$	number of pools in the network that continuously pond ≥5 days during the rainy season.	2
$V_{HEADWATERPOND}$	number of headwater pools that simultaneously hold water at their lowest elevation.	2
$V_{FILLEDMAX}$	the number of headwater basins filled to their maximum depth at least once during the rainy season.	2
V_{BA}	total number of plant species in the basin.	4
$V_{BADI\ 1>0}$	indicator variable for the presence of any species from Category 1 in the pool basin. (0=none, 1=one or more species present). Category 1 includes 5 vernal pool species that are state or federally listed as endangered, threatened or rare. See Table 5.6.	4
$V_{PERIDI\ 12345}$	total number of plant species from distribution categories 1, 2, 3, 4 and 5 that are found in the uplands (20-ft. peripheral band). This includes all species that are not introduced and excludes upland species that are found in the pool basin (Category 6). See Table 5.6.	4
$V_{DI\ 2>0}$	indicator variable for the presence of any species from distribution Category 2 in the pool basin or periphery. (0=none, 1=one or more species present). Category 2 includes 5 basin species and 27 upland species that are narrowly endemic to southern California. If a typical upland species is found in the basin, it is placed in distribution Category 6 rather than Category 2. See Table 5.6.	4
$V_{DI\ 67>17}$	indicator variable for whether there are more than 17 species from distribution Categories 6 & 7 in the pool basin and 20-ft. peripheral band (0=17 or fewer species, 1=18 or more species). If a non-introduced species that is typically found in the uplands/periphery is instead found in the basin, it is placed in Category 6. Category 7 consists of 66 species known to be introduced into the reference domain. See Table 5.6.	4
$V_{CRUSTSPP}$	total number of crustacean species present.	5

(continued)

$V_{FAUNIND}$	proportion of all crustacean species present that are found in the "Faunal Indicators" list of 14 species.	5
V_{SDFS}	indicator variable for the San Diego fairy shrimp, *Branchinecta sandiegonensis*: (0=absent, 1=present).	5
V_{LFS}	indicator variable for the fairy shrimp, *Branchinecta lindahli*: (0=absent, 1=present).	5
Indirect Assessment Variables		
Variable symbol	**Variable definition**	**Function(s) used**
$V_{COBBLESBA}$	100 X (percent of the basin covered with rounded or angular coarse pebbles or cobbles). Pebbles are 2-7.5 cm in diameter and cobbles are 7.5-25 cm in diameter (Soil Survey Manual, USDA 1993).	1, 5
$V_{COBBLESBA>15}$	indicator variable: 0 if $V_{COBBLESBA\leq15}$, 1 if $V_{COBBLESBAS>15}$.	1
$V_{POOLCONNECT}$	indicator variable that characterizes surface connection of the pool to other pools. 1=none, isolated, 2=headwaters (outlet only), 3=flow through (inlet and outlet), 4=terminal, collector (inlet only).	1
$V_{MAXDEPTH}$	maximum depth of the pool in meters, as estimated with surveying equipment.	1, 5
$V_{MAXDEPTH\_GR}$	categorical groups for maximum depth of the pool. $V_{MAXDEPTH\_GR}$= 0.32 if $V_{MAXDEPTH}\leq0.11$ m, = 0.37 if 0.11 m < $V_{MAXDEPTH}$ ≤0.35 m and = 0.00 if 0.35m < $V_{MAXDEPTH}$.	1
V_{LENGTH}	length of longest axis (a) in meters, using the basin edge as determined in the field.	1
V_{SLOPE}	long axis slope= $V_{MAXDEPTH}/(V_{LENGTH})/2)$.	1
V_{SLOPE_GR}	categorical groups for slope: V_{SLOPE}_GR= 1 if $V_{SLOPE}\leq1.9$, =2 if $1.9<V_{SLOPE}\leq3.0$ and =3 if $V_{SLOPE}>3.0$.	1
$V_{DEFIN\_OR\_OUTLET}$	1 if a pool has a defined inlet or defined outlet; 0 otherwise.	1
$V_{IN\_OR\_OUTLET\_WS}$ V_{SLOPE_WS}	variables specific to the water storage function that are calculated based on $V_{POOLCONNECT}$. See Function 1, Indirect Functional Capacity Index, Model Variables.	1
$V_{DIST\ 1km<5}$	indicator variable for whether disturbance in the four 1 km quadrants is less than 5 in all cases. (0=Dist1km-1, Dist1kkm-2, Dist1km-3 and/or Dist1km-4 equal to 6; 1=Dist1km-1, Dist1kkm-2, Dist1km-3 and Dist1km-4 all less than 5). See Chapter 5 "Assessment of Disturbance levels" and Appendix D.2.	1
$V_{NUMPOOLS}$	the number of pools in a network of pools as determined by field surveys.	2
$V_{DOMDISTBA\text{-}NET}$	indicator variable for the dominant disturbance within the basins of a network. See Appendix D.2.	2
$V_{DOMDISTPERI\text{-}NET}$	indicator variable for the dominant disturbance in the 20-ft peripheral band surrounding the basins of a network. See Appendix D.2.	2
$V_{DOMDISTCA\text{-}NET}$	indicator variable for the dominant disturbance in the catchment area of the pool network. See Appendix D.2.	2
$V_{MODIFCAT\text{-}NET}$	indicator variable for the type of modification made to the catchment area of the network. (1= none, 2= draining/diminishment/truncation, 3= addition/augmentation	2

(continued)

$V_{SEDFILLBA\text{-}NET}$	indictor variable for the observable deposition of sediment or fill in the basins of the network as indicated by deltaic deposition patterns or soil discontinuities in texture or color (1= none, 2= < 25% of basin surface, 3= ≥ 25% of basin surface).	2
$V_{INLETELEV\text{-}NET}$	indicator variable for the discernible modification to the inlet elevation of the pools of the network (1= none, 2= raised, 3= lowered, 4= trenched/ditched).	2
$V_{OUTLETELEV\text{-}NET}$	indicator variable for the discernible modification to the outlet elevation of the basins of the network (1= none, 2= raised, 3= lowered, 4= trenched/ditched).	2
$V_{DIST\ 1km<6}$	indicator variable for whether disturbance in the four 1 km quadrants is less than Category 6 in all cases. (0=Dist1km-1, Dist1kkm-2, Dist1km-3 and/or Dist1km-4 equal to 6; 1=Dist1km-1, Dist1kkm-2, Dist1km-3 and Dist1km-4 all less than 6). See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2.	4
$V_{DOMDISTPERI\ -VEG}$	indicator variable for the dominant disturbance in the 20-ft. peripheral band around the basin edge, recoded for the vegetation function (1 = $V_{DOMDISTPERI}$ < 3; 0 = $V_{DOMDISTPERI}$ = 3; -1 = $V_{DOMDISTPERI}$ > 3).	4
$V_{DOMDISTBA=1}$	indicator variable for whether the basin is undisturbed (0=Domdistba greater than one, 1= Domdistba equal to one). See Chapter 5 "Assessment of Disturbance Levels" and Appendix D.2.	4
$V_{MAXDEPTH<0.36m}$	indicator variable for whether $V_{MAXDEPTH}$ <0.36 m (0=$V_{MAXDEPTH}$ greater than or equal to 0.36m, 1=$V_{MAXDEPTH}$ less than 0.36 m).	4
$V_{INLETMOD}$	indicator variable for discernible modification to the basin inlet (0=no, 1=yes).	5
$V_{MOUNDPRES}$	indicator variable for whether mounds are present (0= no, 1= yes).	5
$V_{SURFCRACKS}$	indicator variable for the presence of surface soil cracks (0= no, 1= shallow, 2= deep —deep=> 1cm wide and 1 dm deep).	5
$Log(V_{CATCHAREA})$	logarithm, base 10, of the catchment area estimated in acres.	5
$Log(V_{MAXDEPTH})$	logarithm, base 10, of the maximum depth of the pool in meters, as estimated with surveying equipment.	5
	(concluded)	

Appendix C
Data Collection Forms

C.1. WAA assessment data form

C.2. Pool scale base map Data form

C.3. Landscape level disturbance data form

C.4. Hydrology direct assessment data form

C.5. Hydrologic network direct assessment data form

C.6. Vegetation direct assessment data form

C.7. Fauna (Crustacean) direct assessment data form

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Wetland Assessment Area Data Form

Date_____ Data by _____________________

Location_______________________________________

Conditions_____________________________________

Purpose and General Objectives of the Assessment

Pre-existing Sources of Information

Source	Information obtained

Red Flag Screening Results

List the numbers of items in Table 5.1 that are present. The importance of each red flag may depend on the purpose & objectives of the assessment.

Wetland Assessment Area

Area (acres)__________ Number of pools__________

Description of WAA

Pool sub-class and type

Sub-class ____________________________ Type ______________________________

Justification

Precipitation Regime Context*

Season of assessment ________________ Avg. total seasonal precipitation for the WAA_______

Weather station used for precip. total ___________

Total precipitation up to time of assessment ___________

Precipitation pattern up to time of assessment ____

Continuous ponding events Number _____ Days each event _____________________________

Direct data can be collected for listed functions:____

____

No direct data can be collected__________

* Use the Precipitation Regime Context and Data Collection Guidelines (Appendix D.1).

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Pool Scale Base Map Data Form

Pool #_______________

Date_______ Data by _____________________

Location _________________________________

GPS Coordinates____________________________

Inlets and Outlets

Visible surface inlet(s)
- No_____
- Yes_____
- If yes,
  - Defined channel?_____
  - Swale?_____
  - How supplied?________________
  - Modified?
    - No_____
    - Yes_____
    - If yes,
      - Raised_____ Ditched/trenched_____
      - Lowered_____

Visible surface outlet(s)
- No_____
- Yes_____
- If yes,
  - How many?_____
  - Any modified?
    - No_____
    - Yes_____
      - If yes,
        - Raised_____
        - Lowered_____
        - Ditched/trenched_____

Catchment

Long axis__________ Short axis__________ Area__________

Mounds present? No_____ Yes_____

Basin

Elevations (relative)

Outlet(s)_____ _____ Deepest point__________

Maximum depth (absolute)__________

Edge

Indistinct_____ If distinct, list indicators

Distinct______

__________ __________ __________

__________ __________ __________

Dimensions

Long axis (avg. length)__________ Short axis (avg. length) __________

Long axis slope_______________

Pool area__________ Pool volume__________

Surface features

Cobbles (% cover)__________

Surface cracks No_____ Shallow_____ Deep^_____

^= > 1cm wide & 1 dm deep.

Soil texture

Basin__________ Peripheral band__________

Dominant Disturbance—Basin, Periphery & Catchment

Soil disturbances

Type	Location*	Depth	% cover	DD Category@
______________________	______________	______	______	_____
______________________	______________	______	______	_____
______________________	______________	______	______	_____
______________________	______________	______	______	_____
______________________	______________	______	______	_____
______________________	______________	______	______	_____
______________________	______________	______	______	_____

Dominant Disturbance Category@ Basin_____ Periphery_____ Catchment_____

*=Catchment, Periphery or Basin. @See Table 5.5 and Appendix D.2.

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Landscape Level Disturbance Data Form

Date________ Data by ______________________

Location ___________________________

GPS Coordinates_____________________________________

Basin # ___________

	Q1	Q2	Q3	Q4
	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*
Total				

Basin # ___________

	Q1	Q2	Q3	Q4
	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*
Total				

Basin # ___________

	Q1	Q2	Q3	Q4
	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*
Total				

Basin # ___________

	Q1	Q2	Q3	Q4
	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*
Total				

Basin # ___________

	Q1	Q2	Q3	Q4
	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*	% X Dist Cat*
Total				

* See definitions of Disturbance Categories and sample calculations in Appendix D.2.

SoCal VP Guidebook

Direct Assessment Data Form

Hydrology

Pool #_______ Location__________________________________

Date	Time	Obs.*	Depth or DTW (ft)	HWM validity (E,G,F,P,N,D)	HWM cleaned? (Y or N)	SPECIFIC CONDUCTANCE^ (umhos/cm in field)	SPECIFIC CONDUCTANCE^ (umhos/cm at 25°C)	Field Temp. (°C)	COMMENTS

*Obs.= initials of observer, data taker DTW= Depth to Water E= Excellent, G= Good, F= Fair, P= Poor, N= None and D= doubtful.
For example, excellent means that the HWM is clear, credible and generally observable at more than one location in the pool.
^Not employed in the model FCIs.

SoCal VP Guidebook

Hydrologic Network Data Form

Direct and Indirect Assessment

Network # (if >1 in WAA)_______________

Date_______ Data by _____________________

Location ___________________________________

Indirect Assessment Variables*

Catchment Area Modification-Network

Net change (drained, diminished &/or augmented) _______%

Added to, increased or augmented _______%

Drained, diminished or truncated _______%

Inlet/Outlet modification

Lowered _______# basins Raised _______# basins

Lowered with ditches or trenches _______# basins

____

____

Dominant disturbances @

Basins in the network (Dom dis cat)_____%_____

Basin sediment/fill _____%

Network catchment(Dom dis cat)_____%_____

Periphery of the basins in the network (Dom dis cat)_____%_____

Network size

Number of pools in the network______

Direct Assessment Variables~

Pool #	Network position^	Total days inundated	Inund depth max?	# Precipitation events to pond, with cm/event°
Pool_____				
Pool_____				
Pool_____				
Pool_____				
Pool_____				
Pool_____				
Pool_____				
Pool_____				
Pool_____				
Pool_____				

*Use data on landscape and pool scale base maps and forms.

@ Use Appendix D.2 for Disturbance Categories. ~ Use data from the hydrology direct assessment forms.

^ Connections: 1= isolated, 2= headwater, 3= flowthrough, 4= terminal

° See Table 5.4. May not be needed for FCIs.

SoCal VP Guidebook
Direct Assessment Data Form
Vegetation

Date_____ Pool #_____ Data by ___________________
Location_____________________________________
Conditions______________________________ Page ___

SPECIES	CATEGORY		SPECIES	CATEGORY	
	BA*	PERI*		BA*	PERI*
Pogogyne abramsii	1	1			
Downingia cuspidata	3				
Jepsonia parryi	6	2			
Hypochaeris glabra	7	7			
Agrostis avenacea	7				

* BA= basin, PERI= 20-ft wide band parallel to basin edge.

DISTRIBUTION CATEGORIES

1=**listed**; endangered, threatened or rare (State or Federal list)(excluding category 6).
2=narrow endemic; native to an area south of the Transverse Ranges in California, including Baja MX (excluding category 6).
3=**regional**; native to the California Floristic Province (excluding category 6).
4=**New World, Mediterranean climate**; native to the west coast of N/S America (excluding category 6).
5=**cosmopolitan**; distributed east of the Sierras and/or worldwide, in addition to southern California (excluding category 6). No known introduction into southern California.
6=encroaching upland; species from categories 1-5 that is found in the pool basin but usually occurs in the uplands.
7=**introduced**; known introduction into California.

Definitions and assignments to distribution categories are based primarily on Hickman, James C., ed. 1993. The Jepson manual: Higher plants of California, University of California Press, Berkeley, CA.

VCRUSTSPP Total number of crustacean species present

Record:

USER NOTE: All samples from all dates for the same pool are entered on the same record sheet(s)

Pool number/name/site:

	Sample date	Collected by
Net size (rectang. area)	Lab analysis date	Identified by
Length/depth of sweep 1	Length/depth of sweep 2	Length/depth of sweep 3
Volume of sweep 1	Volume of sweep 2	Volume of sweep 3

For pools > 30 cm deep:

Length/depth of sweep 4	Length/depth of sweep 5	Length/depth of sweep 6
Volume of sweep 4	Volume of sweep 5	Volume of sweep 6
Length/depth of sweep 7	Length/depth of sweep 8	Length/depth of sweep 9
Volume of sweep 7	Volume of sweep 8	Volume of sweep 9

Species name	# found	Species name	# found	Species name	# found

Sample number 2	Date ponding began	
	Sample date	Collected by
Net size (rectang. area)	Lab analysis date	Identified by
Length/depth of sweep 1	Length/depth of sweep 2	Length/depth of sweep 3
Volume of sweep 1	Volume of sweep 2	Volume of sweep 3

For pools > 30 cm deep:

Length/depth of sweep 4	Length/depth of sweep 5	Length/depth of sweep 6
Volume of sweep 4	Volume of sweep 5	Volume of sweep 6
Length/depth of sweep 7	Length/depth of sweep 8	Length/depth of sweep 9
Volume of sweep 7	Volume of sweep 8	Volume of sweep 9

Species name	# found	Species name	# found	Species name	# found

USER NOTE: Duplicate sheet for >2 samples

VCRUSTSPP Total number of crustacean species present **Summary page**

Record:

USER NOTE: All samples from all dates for the same pool are entered on the same record sheet(s)

Pool number/name/site:

Number of samples	Number of ponding events
	Total water volume sampled

Species name	# found	Species name	# found	Species name	# found

VCRUSTSPP	# of Faunal Indicators	VFAUNIND
VLFS		VSDFS

Appendix D
Resources

D.1. Precipitation Regime Context and Data Collection Guidelines

D.2. Disturbance Categories and Sample Calculations

D.3. Coastal SD Vernal Pool Species List

D.4 Guidelines for Assessing the Effects of Proposed Projects on Rare, Threatened, and Endangered Plants and Natural Communities

D.5. Key to CDFG Special Plants List

D.6. Pre-analysis *a priori* FCI descriptions applicable to any function

Appendix D.1. Precipitation Regime Context and Data Collection Guidelines*

1. What season will the assessment will be performed?

    Dormant/drought season—period post-flowering up to the time when sufficient rain has fallen to germinate plants and stimulate regrowth of perennials. Go to 2.

    Growing/rainy season—period following sufficient rainfall to germinate seeds of annual plants and to stimulate regrowth of perennials up to the end of flowering. Go to 3.

2. Was the total precipitation in the preceding rainy/growth season ≥ the long-term average for the assessment area? If not, no direct functional assessments can be performed during the dormant/drought season.

3a. In the year of assessment, has ≥ 14 cm of precipitation fallen?

    If yes, direct assessment of Function 1 (Surface and Sub-Surface Water Storage) can be performed and direct assessment of Function 4 (Plant Community) can be performed by field workers who have experience with the flora over a period of time representing a range of variation in total seasonal precipitation. If <14 cm of precipitation has fallen, direct assessment of Function 1 cannot be performed and direct assessment of Function 4 may not be reliable. Two years of data are recommended.

3b. In the year of the assessment, has sufficient precipitation fallen to meet the criteria for an average to above average or wet year? (See Chapter 4, Function 1 (Surface and Subsurface Water Storage, Direct Functional Capacity Index: Model Variables).

    If yes, a direct assessment can be made of Function 2 (Hydrologic Networks).

3c. In the year of the assessment, has there been continuous ponding ≥ 2 weeks?

    Direct assessment of Function 5 (Faunal Community) may be made with the understanding that all species supported in the community will not be observed without repeat sampling over a period of time. If water has not ponded for at least 2 continuous weeks, direct assessment of Function 5 is not possible.

***These guidelines have been developed and tested on vernal pools in coastal San Diego on soils of pedogenic origin. They may or may not apply to other pool types (age and origin) in different locations (sub-regional climates). See also Table 5.4.**

Appendix D.2. Disturbance Categories* and Sample Calculations

1 minimal disturbance/no disturbance

no known disturbance
light past grazing or brushing
ungraded tracks or trails

2 light to moderate disturbance --not recent, self-recovered or restorable

brushing, blading, disking, cultivation and/or vehicles (not recent)
grazing
trash/dumping
fire
sediment deposition

3 moderate to substantial disturbance --restorable or has been restored; some potential for self-recovery

disking, blading and/or plowing (cultivation)- may or may not be recent
sediment deposition
vehicle damage
landscape altered by roads, culverts, and/or loss of mounds

4 substantial disturbance--restoration potential, but extensive restoration efforts needed

on-going grazing, frequent fires and/or recent blading/brushing
extensive vehicle damage
landscape altered by roads, culverts, and/or loss of mounds
past extensive blading, bulldozing, plowing (cultivation) or grading

5 substantial disturbance--developed or restoration potential low

blading, grading, trenching or filling
extensive development with hard surfaces, roads, culverts
severe or ongoing disturbance (brushing, blading, disking, grading, bulldozing, irrigation, cultivation, vehicles)

6 severe disturbance—surrounding landscape dominated by development, restoration potential minimal to none

deep blading, extensive trenching or ripping
native soil profile no longer evident
artificial landscape dominates, either hardsurface or cultivated turf and landscaping
few or no vestiges of the natural topography

* The disturbance categories are used to score the following variables:

$V_{DIST1km<5}$, $V_{DOMIDISTBA\text{-}NET}$, $V_{DOMDISPERI\text{-}NET}$, $V_{DOMDISCA\text{-}NET}$, $V_{DIST1km<6}$, $V_{DOMDISTPERI\_VEG}$, $V_{DOMDISTBA=1}$.

	Sample calculations of quadrant disturbance scores			
Pool	**Q1**	**Q2**	**Q3**	**Q4**
Pool 1	0.6x1+ 0.4x5= 2.6	0.2x2+ 0.1x6+ 0.7x1= 1.7	.85x2+ .15x4= 2.3	0.75x5+ 0.25x1= 4.0
Pool 2	.20x5+ .35x3+ .45x1= 2.5	.35x2+ .65x6= 4.6	.25x2+ .35x4+ .35x6= 4	.25x4+ .45x1+ .30x2= 2.05

PLANTS THAT IN COASTAL SAN DIEGO COUNTY OCCUR PRIMARILY IN VERNAL POOLS		
SPECIES	INDICATOR CATEGORYΔ	HABITAT DESCRIPTION (CITATION)
Agrostis microphylla	FACW	moist or rather dry open ground (A); vp (B); sometimes vp (J); vp (M); beds & margins of vp, around seepy places (W); common near vp, usually not in basin (Z)
Alopecurus howellii	FACW+	meadows & wet places (A); about drying mud flats (B); wet places, drying mud flats (M); wet ground (MA); vp (P); vernally wet pools & marshes (*T); grassy openings (W); vp (Z)
Anagallis minimus	FACW	moist places (A); vp & other moist spots (B); vp, moist places (J); vp & other moist spots (M) & (M&K); vp (P); vernally wet pools & marshes (T); moist or muddy habitats (W); vp (Z)
Boisduvalia glabella	OBL	dry mud flats & vp (A); vp & other ephemeral ponds (B); floodlands & beds of former vp (MA); mudflats & vp (M); vernally wet pools & marshes (*T); beds of vp on mesas, clay soil in valleys, wet sands of arroyos (W); vp (Z)
Brodiaea orcuttii	OBL	heavy adobe soil on mountains/mesas of SD (A); grass, near v streams & pools (B); grassland near streams, vp (J); streams, vp, seeps (M); vp but not restricted to (P); margins & beds of vp, margins of cienegas (W); vp & adjacent habitats (Z)
Callitriche marginata	OBL	borders of vp in mud or submerged shallow water (A); often vp (J); moist cool places, terrestrial (MA); drying mud of vp (M); vernally wet pools & marshes (*T); muddy margins of vp (W); vp (Z)
Callitriche longipedunculata	OBL	bottom of desiccated winter pools (A); vp (B); rooted aq (MA); water of vp & later on mud (M); vernally wet pools & marshes (*T); vp (Z)
Crassula aquatica	OBL	mud (A); vp, other moist places (B); salt marshes, vp, mudflats, ponds (J); wet ground or vp (MA); dry mud flats (M) vernally wet pools & marshes (T); vp (Z)
Deschampsia danthonioides	FACW	open ground (A); mud flats, vp (B); moist to drying open sites, meadows, streambanks, temporary ponds (J); vp, moist to wet meadows (MA); moist places (M); vp (P); grassy areas (W); vp (T); vp (Z)
Downingia cuspidata	OBL	clay soils of desiccated vp & flats (A); vp (B); vp, lake margins, meadows (J); vp & wet soil (MA); vp (M); vernally wet pools & marshes (T*); margins of vp (W); vp (Z)
Elatine brachysperma	FACW	margins of ponds (A); vp (B); muddy shores, shallow pools (J); shallow water or muddy shores of vp, ponds or ditches (MA); many plant communities (M); vp (P); vernally wet pools & marshes (T*); vp (Z)
Elatine californica	OBL	margins of ponds & pools (A); lake marg, vp (B); pools, ponds, stream banks (J); ponds, vp, rice fields, & margins of streams & ditches (MA); water borders, mudflats (M); vp (P)
Eryngium aristulatum ssp. *parishii*	OBL	vp & salt marshes (A); vp (B); vp (H); vp, marshes (J); vp & salt marshes (MA); vp (M); vp (P); vernally wet pools & marshes (*T); playas & beds of vp (W); vp (Z)
Isoetes howellii	OBL	border of lakes & ponds (A); vp (B); vp, lake margins (J); ponds, streams or vp (MA); in water & on mud (M) & (M&K); vp (P); vernally wet pools & marshes (*T); along streams & in shallow pools (W); vp (Z)
Isoetes orcuttii	OBL	mesas in low depressions (A); vp, ephemeral ponds (B); vp (J); margins of pools or along streams (MA); water of vp & on mud (M); water of vp (M&K); vp on mesas & plateaus (W); vp (Z)
Juncus triformis	FACW	moist places (A); vp, ephemeral ponds (B); vp, granitic seeps (J); moist open places (M); vp (P); vp (T*); vp & other aquatic, marsh, orseepage areas (Z)

PLANTS THAT IN COASTAL SAN DIEGO COUNTY OCCUR PRIMARILY IN VERNAL POOLS		
SPECIES	INDICATOR CATEGORYΔ	HABITAT DESCRIPTION (CITATION)
Lepidium latipes	OBL	alkaline flats or balsas (A); ephemeral ponds (B); alkaline soils, fields, vp, grasslands (J); former beds of alkaline pools (MA); alkaline flats & beds of winter pools (M); vernally wet pools & marshes (*T); vp & adjacent habitats (Z)
Lilaea scilloides	OBL	mud about lakes, pools & slow running streams (A); shallow ponds, slow streams, vp (B); vp, ditches, streams, ponds, lake margins < 1700 m (J); wet soil around ponds, lakes, streams (MA); muddy & marshy places (M); vp (P); vp (T); mud around lakes, ponds & vp (W); vp (Z)
Lythrum hyssopifolia	FACW	moist ground (A); vp, other moist places (B); marshes, drying pond edges (J); wet soil in marshes & at margins of streams & ponds (MA); moist places (M); vp (P); vernally wet pools & marshes (*T); vp (Z)
Marsilea vestita	OBL	edge of ponds, ditches & rivers (A); ponds & reservoirs (B); creek beds, flood basins, vp (J); muddy banks, edges of ponds, esp about vp (M); ponds & ditches (MA); vernally wet pools & marshes (T); vp (Z)
Mimulus latidens	OBL	wet adove soil (A); vp (B); vernally wet depressions < 900 m (J); drying mud flats in heavy soil (M); wet adobe & clay soil, margins of vp (W); vp (Z)
Myosurus minimus var. *apus*	OBL	mesas back of SD (A); vp (B); vp (H); wet places, vp, marshes (#J); vp & alkaline marshes (MA); vp (M); vp (P); vernally wet pools & marshes (#T); vp (#Z)
Myosurus minimus var. *filiformis*	OBL	moist places (A); vp (B); vp (H); wet places, vp, marshes (#J); vp & vernally wet meadows (MA); vp (M); vp (P); vernally wet pools & marshes (#T); grassy hillsides (W); vp (#Z)
Navarretia fossalis		species not described (A); vp & ditches (B); vp (H); vp & ditches (J); vernally wet pools & marshes (*T); vp & man-made depressions & pools (W); vp & adjacent habitats (Z)
Navarretia intertexta	OBL	no habitat given (A); wet meadows & muddy shorelines (B); open wet areas, meadows, vp (J); vps & moist places (M) & (M&K); drying vp (W); common near vp, usually not in basin (Z)
Navarretia prostrata	OBL	no habitat given (A); Kearny Mesa (B); alkaline floodplains, vp (J); vp & low places (MA); vp & moist places (M); vp (Z)
Orcuttia californica	OBL	no habitat given (A); vp & slump ponds (B); vp (H); vp (J); vp & mud flats (MA); drying mud flats (M); vernally wet pools & marshes (*T);drying beds of vp (W); vp (Z)
Phalaris lemmonii	FACW-	no habitat given (A); mud flats, vp (B); moist areas, shrublands, woodlands (J); low wet places, dried mud flats (MA); moist places < 2000 ft (M); vp (P); vernally wet pools & marshes (*T); creosote bush scrub (W); vp (Z)
Pilularia americana	OBL	clayey depressions & desiccating pools (A); vp, ephemeral ponds (B); vp, mud flats, lake margins, reservoirs (J); margins of ponds & vp (MA); occasional in heavy soil, largely of vp (M); vp (P); vernally wet pools & marshes (T); in water on mesas (W); vp (Z)
Plagiobothrys acanthocarpus	OBL	vp & adobe flats (A); mesas & vp (B); vp, moist clay soils (J); vp & adobe flats (MA); moist flats, winter pools (M); vernally wet pools & marshes (*T); vp (Z)
Plagiobothrys bracteatus	OBL	dry beds of pools & ditches (A); vernally moist places (B); vp, wet places in grassland (J); wet places (MA); moist places or dried ditches (M); moist places or beds of pools & ditches, <5000 ft (M&K); vp (P); vp (Z)
Plagiobothrys undulatus		moist adobe or dry soils in valleys & mesas near the coast (A); vp near Ramona (B); moist places & beds of vp (MA); mud flats, < 1200 ft (M&K); vp (Z)

PLANTS THAT IN COASTAL SAN DIEGO COUNTY OCCUR PRIMARILY IN VERNAL POOLS		
SPECIES	INDICATOR CATEGORYΔ	HABITAT DESCRIPTION (CITATION)
Plantago bigelovii	OBL	salt marshes along coast & inland alkaline flats (A); vp (B); saline & alkaline places, beaches, vp (J); saline & alkaline places (M); vp (P); vp & adjacent habitat (Z)
Pogogyne abramsii	OBL	dried bottom of winter rain pools, on mesas n of SD (A); vp (B); vp (H); vp coastal terraces (J); beds of dried pools (M) & (M&K); vernally wet pools & marshes (*T); vp (Z)
Pogogyne nudiuscula	OBL	dry bottom of winter pools (A); vp (B); vp (H); vp (J); beds of vp (MA); moist flats (M) & (M&K); dry beds of vp (W); vp (Z)
Psilocarphus brevissimus	OBL	dried beds of vp & moist places (A); ponds (B); vp & flats (J); dried beds of vp (MA) & (M); vp (P); dried beds of vp (W); vernally wet pools & marshes (*T); vp (Z)
Psilocarphus tenellus	FAC	dried vp & dry open places (A); shores of drying ponds (B); dry disturbed soil, rarely vp (J); drier habitats (MA); dried vp (M) & (M&K); vp (P); foothills & mesas (W); vp (Z)
Sibara virginica	OBL*	desiccated vp (A); ephemeral ponds (B); borders of vp, streambanks, open ground (J); about drying pools (M); vp (Z)

PLANTS THAT ARE COMMON IN COASTAL SAN DIEGO VERNAL POOLS, BUT NOT RESTRICTED TO POOLS		
SPECIES	INDICATOR CATEGORYΔ	HABITAT DESCRIPTION (CITATION)
Bergia texana	OBL	moist ground (A); moist, disturbed soils, sand bars along rivers, margins of pools (J); margins of pools or floodplains (MA); occasional on mud flats (M); at margins of pools & on seeps (W)
Brodiaea jolonensis		species not described (A); grass (B); grassland, foothill woodland on clay (J); clay depressions (M); depressions in clay soil (W); vp & adjacent habitats (Z)
Cotula coronopifolia	FACW+	tidal flats along the coast, inland in wet places (A); wet places (B); saline & freshwater marshes (J); marshy, often almost aquatic; freq salt marshes (MA); mud & moist banks, salt marshes (M); vp (P); wet places & water margins (W); vp & other aquatic, marsh & seepage areas (Z)
Cressa truxillensis	FACW	saline soils (A); alkaline areas (B); saline & alkaline soils (J); lowland alkaline areas (MA); saline & alkaline places (M); alkaline or moderately saline soils (W); vp & other aquatic, marsh & seepage areas (Z)
Eleocharis acicularis	OBL	moist grounds (A); moist habitats (B); muddy river banks, meadows, vp & marshes (MA); marshes, meadows, riverbankds, vp (J); muddy banks, meadows, vp & marshes (M) & (M&K); widespread (W); vp & other aquatic, marsh & seepage areas (Z)
Eleocharis macrostachya	OBL	moist soil (A); wet places (B); marshes, pond margins, vp, ditches (J); marshes, vp, ditches, flooded lands (MA); marshes & wet places (M); vp (P); along pools & intermittent streams (W); vp & other aquatic, marsh & seepage areas (Z)
Gastridium ventricosum	FACU	open ground & waste places (A); weed (B); open, generally dry, disturbed sites (J); dry ground, along streams, vp (MA); weed (M); around vp, on grassy slopes (W); vp & adjacent habitats (Z)

PLANTS THAT ARE COMMON IN COASTAL SAN DIEGO VERNAL POOLS, BUT NOT RESTRICTED TO POOLS		
SPECIES	INDICATOR CATEGORYΔ	HABITAT DESCRIPTION (CITATION)
Juncus bufonius	FACW+	dried up pools, border of streams (A); wet habitats (B); moist (sometimes saline) open or disturbed places (J); along streams or in dried pools (MA); moist, open places (M); vp but not restricted to (P); vp & other aquatic, marsh & seepage areas (Z)
Juncus dubius	FACW*	mountain meadows & stream bankds (A); wet places < 1100 ft (B); wet places (J); moist places (M); wet places (M&K);
Lepidium nitidum		vp (P); stream banks (W) grassy hills, valleys & plains (A); open places (B); meadows, alkaline flats, vp, < 1500 m (J); open places (M); vp but not restricted to (P); open grassy plains & hillsides (W); vp & adjacent habitats (Z)
Lolium perenne	FAC*	roadsides & waste places (A); weed (B); disturbed sites, abandoned fields, lawns (J); scattered (M); weed (W); vp & adjacent habitats (Z)
Montia fontana	OBL	floating in streams or drying pools (A); shaded slopes, pool margins, montane (B); ponds, streams, vp, seeps, ditches, <3200 m (J); muddy stream margins, pools (MA); rain pools (M); muddy stream margins, floating in pools (MA); vp & other aquatic, marsh & seepage areas (Z)
Nama stenocarpum	OBL	muddy shores of lakes & on river banks (A); muddy shore of ponds & lakes, < 300 m (B); intermittently wet areas (J); occasional, muddy places < 1000 ft (M); moist sand in arroyos, canyons & valley floors, basins of vp, deltas (W)
Navarretia hamata		no habitat given (A); coastal sage scrub, chaparral (B); dry, sandy, rocky places (J); dry, rocky places (M) vp but not restricted to (P); dry hillsides & ridges (W); near, but usually not in vp (Z)
Ophioglossum californicum	FACW	moist stony mesas (A); grass, around vp (B); vp (H); grassy pastures, chaparral, vp margins (J); vp (M) & (M&K); moist habitats, often margins of vp (W); near but not usually in vp (Z)
Plantago erecta		grassy hillsides & flats (A); around vp (B); vp (P); dry open places (M) & (M&K); grassy hillsides (W); vp & adjacent habitats (Z)
Polypogon monspeliensis	FACW+	waste places & along irrigating ditches (A); weed moist places (B); moist places, along streams, ditches (J); moist places (MA); weed low places (M); disturbed soil & other grassy areas (W); vp & other aquatic, marsh & seepage areas (Z)
Rotala ramosior	OBL	swamps & edges of ponds (A); irrigated fields, lake & pond margins, streams (J); wet places, < 4000 ft (MA)
Trifolium amplectans		grassy hillsides & valleys (A); grass (B); wet meadows, ditches, grasslands, roadsides, open spring-moist heavy soils (J); grassy places (M); grassy areas (W); vp & adjacent habitats (Z)
Verbena bracteata	FACW	roadsides & waste places in heavy or sandy soil (A); wet places, < 150 m (B); open, disturbed places, pond or lake margins (J); near water in marshes, floodlands (MA); occasional in waste places, < 5000 ft (M); waste areas (W)
Veronica peregrina	OBL	moist ground (A); not habitat given (B); moist places < 3100 m (J); wet places on margins of ditches & ponds (MA); moist places (M); vp (P); moist habitats (W); vp & other aquatic, marsh & seepage areas (Z)

Citations: A= Abrams (1940, 1944, 1951 & 1960), B= Beauchamp (1986), H= Holland (1986), J= Hickman (1993), MA= Mason (1957), M= Munz (1974), M & K= Munz & Keck (1968), P= Purer (1937), T= Thorne (1976), W= Wiggins (1980) and Z= Zedler (1987)
Δ Fish and Wildlife Service (1988)
*T when Thorne (76) gives genus only; # when no subspecies is given

Appendix D.3. Coastal SD Vernal Pool Species List (compiled by E.T. Bauder, SDSU, for the City of San Diego Wetlands Advisory Board, 6/93, rev 2/97 & 5/05).

Guidelines for Assessing the Effects of Proposed Projects on Rare, Threatened, and Endangered Plants and Natural Communities*

State of California
THE RESOURCES AGENCY
Department of Fish and Game
December 9, 1983
Revised May 8, 2000
[Note: Update in process June 2009]

The following recommendations are intended to help those who prepare and review environmental documents determine **when** a botanical survey is needed, **who** should be considered qualified to conduct such surveys, **how** field surveys should be conducted, and **what** information should be contained in the survey report. The Department may recommend that lead agencies not accept the results of surveys that are not conducted according to these guidelines.

1. Botanical surveys are conducted in order to determine the environmental effects of proposed projects on all rare, threatened, and endangered plants and plant communities. Rare, threatened, and endangered plants are not necessarily limited to those species which have been "listed" by state and federal agencies but should include any species that, based on all available data, can be shown to be rare, threatened, and/or endangered under the following definitions:

   A species, subspecies, or variety of plant is "endangered" when the prospects of its survival and reproduction are in immediate jeopardy from one or more causes, including loss of habitat, change in habitat, over-exploitation, predation, competition, or disease. A plant is "threatened" when it is likely to become endangered in the foreseeable future in the absence of protection measures. A plant is "rare" when, although not presently threatened with extinction, the species, subspecies, or variety is found in such small numbers throughout its range that it may be endangered if its environment worsens.

   Rare natural communities are those communities that are of highly limited distribution. These communities may or may not contain rare, threatened, or endangered species. The most current version of the California Natural Diversity Database's List of California Terrestrial Natural Communities may be used as a guide to the names and status of communities.

2. It is appropriate to conduct a botanical field survey to determine if, or to the extent that, rare, threatened, or endangered plants will be affected by a proposed project when:

   a. Natural vegetation occurs on the site, it is unknown if rare, threatened, or endangered plants or habitats occur on the site, and the project has the potential for direct or indirect effects on vegetation; or
   b. Rare plants have historically been identified on the project site, but adequate information for impact assessment is lacking.

3. Botanical consultants should possess the following qualifications:

   a. Experience conducting floristic field surveys;
   b. Knowledge of plant taxonomy and plant community ecology;
   c. Familiarity with the plants of the area, including rare, threatened, and endangered species;
   d. Familiarity with the appropriate state and federal statutes related to plants and plant collecting; and,

e. Experience with analyzing impacts of development on native plant species and communities.

4. Field surveys should be conducted in a manner that will locate any rare, threatened, or endangered species that may be present. Specifically, rare, threatened, or endangered plant surveys should be:

   a. Conducted in the field at the proper time of year when rare, threatened, or endangered species are both evident and identifiable. Usually, this is when the plants are flowering.

      When rare, threatened, or endangered plants are known to occur in the type(s) of habitat present in the project area, nearby accessible occurrences of the plants (reference sites) should be observed to determine that the species are identifiable at the time of the survey.

   b. Floristic in nature. A floristic survey requires that every plant observed be identified to the extent necessary to determine its rarity and listing status. In addition, a sufficient number of visits spaced throughout the growing season are necessary to accurately determine what plants exist on the site. In order to properly characterize the site and document the completeness of the survey, a complete list of plants observed on the site should be included in every botanical survey report.

   c. Conducted in a manner that is consistent with conservation ethics. Collections (voucher specimens) of rare, threatened, or endangered species, or suspected rare, threatened, or endangered species should be made only when such actions would not jeopardize the continued existence of the population and in accordance with applicable state and federal permit requirements. A collecting permit from the Habitat Conservation Planning Branch of DFG is required for collection of state-listed plant species. Voucher specimens should be deposited at recognized public herbaria for future reference. Photography should be used to document plant identification and habitat whenever possible, but especially when the population cannot withstand collection of voucher specimens.

   d. Conducted using systematic field techniques in all habitats of the site to ensure a thorough coverage of potential impact areas.

   e. Well documented. When a rare, threatened, or endangered plant (or rare plant community) is located, a California Native Species (or Community) Field Survey Form or equivalent written form, accompanied by a copy of the appropriate portion of a 7.5 minute topographic map with the occurrence mapped, should be completed and submitted to the Natural Diversity Database. Locations may be best documented using global positioning systems (GPS) and presented in map and digital forms as these tools become more accessible.

5. Reports of botanical field surveys should be included in or with environmental assessments, negative declarations and mitigated negative declarations, Timber Harvesting Plans (THPs), EIR's, and EIS's, and should contain the following information:

   a. Project description, including a detailed map of the project location and study area.

   b. A written description of biological setting referencing the community nomenclature used and a vegetation map.

   c. Detailed description of survey methodology.

d. Dates of field surveys and total person-hours spent on field surveys.

e. Results of field survey including detailed maps and specific location data for each plant population found. Investigators are encouraged to provide GPS data and maps documenting population boundaries.

f. An assessment of potential impacts. This should include a map showing the distribution of plants in relation to proposed activities.

g. Discussion of the significance of rare, threatened, or endangered plant populations in the project area considering nearby populations and total species distribution.

h. Recommended measures to avoid impacts.

i. A list of all plants observed on the project area. Plants should be identified to the taxonomic level necessary to determine whether or not they are rare, threatened or endangered.

j. Description of reference site(s) visited and phenological development of rare, threatened, or endangered plant(s).

k. Copies of all California Native Species Field Survey Forms or Natural Community Field Survey Forms.

l. Name of field investigator(s).

m. References cited, persons contacted, herbaria visited, and the location of voucher specimens.

*Source: California Department of Fish and Game, Natural Diversity Database. April 2009. Special Vascular Plants, Bryophytes, and Lichens List. Quarterly publication. 71 pp. (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/SPPlants.pdf)

Appendix D.4. Guidelines for Assessing the Effects of Proposed Projects.

SPECIAL PLANTS

Last updated March 23, 2007*

California Natural Diversity Database (CNDDB)

California Department of Fish and Game

"Special Plants" is a broad term used to refer to all the plant taxa inventoried by the Department of Fish and Game's California Natural Diversity Database (CNDDB), regardless of their legal or protection status. Special Plants include vascular plants and high priority bryophytes (mosses, liverworts, and hornworts) which are a recent addition. Special Plant taxa are species, subspecies, or varieties that fall into one or more of the following categories:

- Officially listed by California or the Federal Government as Endangered, Threatened, or Rare;

- A candidate for state or federal listing as Endangered, Threatened, or Rare;

- Taxa which meet the criteria for listing, even if not currently included on any list, as described in Section 15380 of the California Environmental Quality Act (CEQA) Guidelines; these taxa may indicate "none" under listing stats, but note that all CNPS List 1 and 2 and some List 3 plants may fall under Section 15380 of CEQA.

- A Bureau of Land Management, U.S. Fish and Wildlife Service, or U.S. Forest Service Sensitive Species;

- Taxa listed in the California Native Plant Society's *Inventory of Rare and Endangered Plants of California*;

- Taxa that are biologically rare, very restricted in distribution, or declining throughout their range but not currently threatened with extirpation;

- Population(s) in California that may be peripheral to the major portion of a taxon's range but are threatened with extirpation in California; and

- Taxa closely associated with a habitat that is declining in California at a significant rate (e.g., wetlands, riparian, vernal pools, old growth forests, desert aquatic systems, native grasslands, valley shrubland habitats, etc.).

This list contains taxa that are actively inventoried by the CNDDB (Note: GIS'ed taxa have a "yes" in the right column of the list) as well as an almost equal number of taxa which it tracks but as yet has only quad and county level geographic information.

For the latter taxa, we [**CNDDB**] maintain site and other information in manual files along with internet access to the quad and county level information via our "**CNDDB Quick Viewer**." These plants will be added to the computerized inventory as time permits or when we have enough information to determine that they fulfill our rarity and/or endangerment criteria. For more copies of this list or other CNDDB information, call (916) 324-3812 or email Kristina Donat, Information

Services, at kdonat@dfg.ca.gov.

NOTE: We [**CNDDB**] have removed the designation "**Federal Species of Concern**." Please do not be concerned; the federal species of concern list was an internal FWS list maintained by their Sacramento office of taxa that were formerly designated C1 and C2 plus some other miscellaneous taxa. Once we discovered that the list was seldom updated and generated only from Sacramento without review by other FWS offices, we decided we were not doing you a service by including this designation. The taxa are just as important as before and should be given consideration in your environmental work.

California Heritage (CNDDB) Element Ranking For Plants

Last updated March 23, 2007

All Heritage Programs, such as the California Natural Diversity Database (CNDDB) use the same ranking methodology, originally developed by The Nature Conservancy and now maintained by Natureserve. It includes a **Global rank** (G rank), describing the rank for a given taxon over its entire distribution and a **State rank** (S rank), describing the rank for the taxon over its state distribution. For subspecies and varieties, there is also a "T" rank describing the global rank for the subspecies. The second page of this document details the criteria used to assign element ranks, from G1 to G5 for the Global rank and from S1 to S5 for the State rank. Procedurally, state programs such as the CNDDB develop Global ranks which are checked for consistency and logical errors by Natureserve at the national level.

The first step to ranking is based on *rarity*, and involves counting total occurrences, counting the number of "good" (highly ranked) occurrences and counting individuals for a given plant. An occurrence for a plant is defined as any population or group of nearby populations located more than 0.25 miles from any other population. Element occurrences can be ranked A-D, depending on apparent degree of viability and habitat condition. Usually the two biggest factors are population size and habitat quality. However, there is more to ranking than just counting element occurrences and individuals. Some of the other considerations specific to plants or lichens include:

- An aerial view of the extent of the distribution. Is the taxon very narrowly distributed (even if it has lots of occurrences), or is it scattered over a wide area?
- Are the element occurrences very large, very small, or mixed in size? Are small occurrences viable over time?
- What is the total acreage of the element occurrences?
- Is the element located in a vulnerable habitat type, such as in wetlands?
- What aspects of the biology and ecology of the element should we consider when ranking it? Some aspects to consider are life form, life span, demographic concerns, persistence of seed bank, reaction to disturbance, dependence on pollinators or seed dispersal agents, restriction to soil type and other "niche breadth" concerns, and more.
- Is anything known about trends for the element? Do we think the species is increasing, decreasing or stable?

With the above considerations in mind, refer to the next page for the numerical definitions for G1-5 and S1-5. A taxon's ranking status may be adjusted up or down depending upon the considerations above.

ELEMENT RANKING

GLOBAL RANKING

The *global rank* (G-rank) is a reflection of the overall condition of an element throughout its global range.

SPECIES OR NATURAL COMMUNITY LEVEL

G1 = Less than 6 viable element occurrences (Eos) OR less than 1,000 individuals OR less than 2,000 acres.
G2 = 6-20 Eos OR 1,000-3,000 individuals OR 2,000-10,000 acres.
G3 = 21-80 Eos OR 3,000-10,000 individuals OR 10,000-50,000 acres.
G4 = Apparently secure; this rank is clearly lower than G3 but factors exist to cause some concern; i.e., there is some threat, or somewhat narrow habitat.
G5 = Population or stand demonstrably secure to ineradicable due to being commonly found in the world.

SUBSPECIES LEVEL

Subspecies receive a **T-rank** attached to the G-rank. With the subspecies, the G-rank reflects the condition of the entire species, whereas the T-rank reflects the global situation of just the subspecies or variety. For example: *Chorizanthe robusta* var. *hartwegii*. This plant is ranked G2T1. The G-rank refers to the whole species range i.e., *Chorizanthe robusta.* The T-rank refers only to the global condition of var. *hartwegii*.

STATE RANKING

The *state rank* (S-rank) is assigned much the same way as the global rank, except state ranks in California often also contain a threat designation attached to the S-rank.

S1 = **Critically Imperiled—**Critically imperiled in the site because of extreme rarity (often 5 or fewer occurrences) or because of some factor(s) such as very steep declines making it especially vulnerable to extirpation from the state/province**.**
S2 = **Imperiled**—Imperiled in the state because of rarity due to very restricted range, very few populations (often 20 or fewer), steep declines, or other factors making it very vulnerable to extirpation from the nation of state/province
S3 = **Vulnerable**—Vulnerable in the state due to a restricted range, relatively few populations (often 80 or fewer), recent and widespread declines, or other factors making it vulnerable to extirpation.
S4 = **Apparently Secure**—Uncommon but not rare; some cause for long-term concern due to declines or other factors.
S5 = **Secure**—Common, widespread, and abundant in the state.

Notes:

<table>
<tr><td>1.</td><td>Other considerations used when ranking a species or natural community include the pattern of distribution of the element on the landscape, fragmentation of the population/stands, and historical extent as compared to its modern range. It is important to t</td><td rowspan="2">3.</td><td rowspan="2">Other symbols:

GH All sites are historical; the element has not been seen for at least 20 years, but suitable habitat still exists (SH = All California sites are historical).

GX All sites are extirpated; this element is extinct in the wild (SX =

GXC Extinct in the wild; exists in cultivation.

G1Q The element is very rare, but there are taxonomic questions associated with it.

T Rank applies to a subspecies or variety.</td></tr>
<tr><td>2.</td><td>Uncertainty about the rank of an element is expressed in two major ways:

By expressing the ranks as a range of values: e.g., S2S3 means the rank is somewhere between S2 and S3.

By adding a ? to the rank: e.g., S2? This represents more certainty than S2S3, but less certainty than S2.</td></tr>
</table>

SPECIAL LICHENS

Last updated March 23, 2007

There are a few lichens in California for which we [**CNDDB**] have adequate information to place them on the list of Special taxa. They appear after the bryophytes at the beginning of the list. We are not including lichens for which little is known, even if they are only known from a few sites in California because the level of information is not developed enough. As information on individual taxa becomes better developed, more lichens may be added. Lichen statuses are developed in coordination with the California Lichen Society (CALS) and relevant experts

Note that lichens are not plants, but a symbiotic relationship between a fungus and either green algae or cyanobacteria (aka bluegreen algae).

The California Native Plant Society's (CNPS) Lists

- **1A. Presumed extinct in California**
- **1B. Rare or Endangered in California and elsewhere**
- **2. Rare or Endangered in California, more common elsewhere**
- **3. Plants for which we need more information - Review list**
- **4. Plants of limited distribution - Watch list**

List 1A: Plants Presumed Extinct in California

The plants of List 1A are presumed extinct because they have not been seen or collected in the wild in California for many years. Although most of them are restricted to California, a few are found in other states as well. In many cases, repeated attempts have been made to rediscover these plants by visiting known historical locations. Even after such diligent searching, we are constrained against saying that they are extinct, since for most of them rediscovery remains a distinct possibility. Note that care should be taken to distinguish between "extinct" and "extirpated." A plant is extirpated if it has been locally eliminated, but it may be doing well elsewhere in its range.

List 1B: Plants Rare, Threatened, or Endangered in California and Elsewhere.

The plants of List 1B are rare throughout their range. All but a few are endemic to California. All of them are judged to be vulnerable under present circumstances or to have a high potential for becoming so because of their limited or vulnerable habitat, their low numbers of individuals per population (even though they may be wide ranging), or their limited number of populations. Most of the plants of List 1B have declined significantly over the last century.

List 2: Plants Rare, Threatened, or Endangered in California, but More Common Elsewhere

Except for being common beyond the boundaries of California, the plants of List 2 would have appeared on List 1B. From the federal perspective, plants common in other states or countries are not eligible for consideration under the provisions of the Endangered Species Act. Until 1979, a similar policy was followed in California. However, after the passage of the Native Plant Protection Act, plants were considered for protection without regard to their distribution outside the state.

List 3: Plants About Which We Need More Information - A Review list

The plants that comprise List 3 are united by one common theme--we lack the necessary information to assign them to one of the other lists or to reject them. Nearly all of the plants remaining on List 3 are taxonomically problematic.

List 4: Plants of Limited Distribution - A Watch list

The plants in this category are of limited distribution or infrequent throughout a broader area in California, and their vulnerability or susceptibility to threat appears low at this time. While we cannot call these plants "rare" from a statewide perspective, they are uncommon enough that their status should be monitored regularly. Should the degree of endangerment or rarity of a List 4 plant change, we will transfer it to a more appropriate list or deleted from consideration.

Threat ranks:
Recently, CNPS added a decimal threat rank to the List ranks to parallel that used by the CNDDB. This extension replaces the E (Endangerment) value from the R-E-D Code. CNPS ranks therefore read like this: 1B.1, 1B.2, etc.

New Threat Code extensions and their meanings:

.1 - Seriously endangered in California

.2 – Fairly endangered in California

.3 – Not very endangered in California
Note that all List 1A (presumed extinct in California) and some List 3 (need more information- a review list) plants lacking any threat information receive no threat code extension. Also, these Threat Code guidelines represent a starting point in the assessment of threat level. Other factors, such as habitat vulnerability and specificity, distribution, and condition of occurrences, are also considered in setting the Threat Code.

*Source: California Department of Fish and Game, Natural Diversity Database. April 2009. Special Vascular Plants, Bryophytes, and Lichens List. Quarterly publication. 71 pp. (http://www.dfg.ca.gov/biogeodata/cnddb/pdfs/SPPlants.pdf)

Appendix D.5. Key to CDFG Special Plants List.

Appendix D.6. Pre-analysis *a priori* FCI Descriptions Applicable to Any Function
1.0 = <u>Pool is functioning at its optimum level and will do so for the foreseeable future.</u> Defined practically as the amount (and kind) of function characteristic for pools in the subclass that are of the same type (Table 5.2), location (Table 3.1) and landscape position (VPOOLCONNECT, Appendix B) in the absence of disturbance to both basin and uplands (periphery and catchment). This will usually occur when there is no known disturbance, light past grazing or brushing, or ungraded tracks or trails. However, a score of 1.0 may be possible for some functions even when more severe disturbance has occurred.
0.75 = <u>Pool is functioning at its highest level but is declining, or is functioning at near-optimal levels and will do so for the foreseeable future.</u> a. The pool is fully functional but biotic and/or abiotic features of the pool or surrounding landscape make it very likely that this functionality cannot be sustained. Restored or created pools are typically unstable for a number of years. They may or may not sustain function at this level. Various other features contributing to functional decline could include disturbance, demographic or other ecological processes affecting native species, increasing frequency of invasive species, or hydrological changes. For example, vernal pools may retain characteristic flora and fauna for some period of time after dramatic hydrologic impacts have taken place, due to the moderating effects of older dormant propagules. b. Full functionality is not found, but at least the major characteristics of the function have been captured. Functionality is not in decline. Pools in this category will typically have minimal disturbance to basin and/or moderate disturbance to uplands (periphery and catchment). Pools that are demonstrably self-recovering from previous disturbances such as limited fill, trenching, agriculture, fire and/or vehicles are likely to have a score of 0.75.
0.65 = <u>Pool has high functionality, is declining, but is recoverable. Alternatively, the pool retains some functionality, is stable or improving, and is recoverable with moderate external effort.</u> a. Full functionality is not found, but at least the major characteristics of the function have been captured. Functionality is declining or unstable, often due to ongoing disturbances or in connection with restoration, enhancement or creation activities. Pools in this category will typically have moderate disturbance to the basin and moderate to high disturbance to uplands (periphery and catchment). The pool can be restored or stabilized with moderate effort. Removal of ongoing disturbances would likely lead to self-recovery and improved function. b. Substantial functionality has been lost, typically due to moderate to substantial disturbance in the basin and uplands. Possible sources include draining, dams, filling, trenching, severe agricultural alterations or vehicle damage. The pool is improving in function or at least stable. Restoration to a higher level of function is feasible.
0.5 = <u>Pool retains moderate function, but is in decline or stable. Restoration to near full function is feasible with extensive effort or pool has undergone major restoration. If portions of the catchment are developed or un-restorable, it is unlikely that full or substantially improved function can be achieved.</u> a. Significant functionality has been lost, typically due to moderate to substantial on-going or recent disturbance in the basin and uplands. Possible sources of disturbance include draining, dams, filling, trenching, severe agricultural alterations or vehicle damage. The pool is declining in function but restoration is feasible with extensive effort. Removal of ongoing disturbances could result in self-recovery and improved function. b. Significant functionality has been lost, typically due to moderate to substantial disturbance in the basin and uplands, often in the past rather than recently. The pool is stable or possibly improving. Restoration to near full functionality would require extensive effort. c. Full functionality is not found, but the major characteristics have been restored and ongoing disturbance has been removed. Uplands and the watershed have been restored or are mostly intact. Level of function may or may not be sustainable.

0.25 = Pool retains some function, but is declining and not recoverable. Alternatively, the pool has low function but has some potential for self-recovery or restoration. If portions of the catchment are developed or un-restorable, it is unlikely that substantially improved function can be achieved.

a. Significant functionality has been lost, typically due to moderate to substantial disturbance in the basin and uplands. The pool is in decline. If ongoing disturbances are removed, function could improve, but restoration potential is limited and restoration would require extreme effort.
b. Function is low because there is substantial disturbance to basin, periphery and catchment. Mounds may have been lost due to blading or grading. Shape and soil surface of basin may be severely impacted. There may be permanent changes to the pool and surrounding landscape, such as domination of the landscape by hard surfaces, or severe hydrological and physical disturbances. The pool is stable or in the process of limited self-recovery or at least restoration to better functionality is feasible.

0.1 = Pool has low function, severe on-going disturbance and/or is probably incapable of recovery due to severe disturbance.

a. Function is low because there is substantial disturbance to basin, periphery and catchment. Mounds may have been lost due to blading or grading. Shape and soil surface of basin may be severely impacted. There may be permanent changes to the pool and surrounding landscape, such as domination of the landscape by hard surfaces or severe hydrological and physical disturbances. If low levels of functionality are stable, then it is clear that restoration potential is minimal (even with a large expenditure of resources). It is more likely that the pool is in decline towards zero functionality. There may be few or no vestiges of the natural basin and mound topography, and the native soil profile of uplands and basin is no longer evident.

0.0 = Pool retains no functionality.