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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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

<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 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

<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: $32.1 \le V_{TOTPRECIP}$						
$V_{TOTINUND}$	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 = $(0.08 \times V_{COBBLESBA>15}) + (0.35 \times V_{DIST1km<5}) + V_{MAXDEPTH\_GR} + V_{IN\_OR\_OUTLET\_WS} + V_{SLOPE\_WS}$

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). 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	
$V_{SEDFILLBA-NET}$	
Measurement or condition- $V_{SEDFILLBA-NET}$	**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
$V_{INLETELEV-NET}$ and $V_{OUTLETELEV-NET}$	
Measurement or condition- $V_{INLETELEV-NET}$ and $V_{OUTLETELEV-NET}$	**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= ($V_{NUMPOOLS}$ + $V_{DOMDISTBA-NET}$ + $V_{DOMDISTPERI-NET}$ + ($V_{DOMDISTCA-NET}$ /2) ($V_{MODIFCAT-NET}$/2) +$V_{SEDFILLBA-NET}$+ $V_{INLETELEV-NET}$ + $V_{OUTLETELEV-NET}$) /7	
* Scoring of variables is more fully explained on the data forms in Appendix C.	

Index of Function

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

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.

Direct Functional Capacity Index

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.

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

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.

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 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 $V_{MAXDEPTH}$

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:

$$\text{Indirect FCI} = 0.30 + (0.50 \times (V_{INLETMOD} = 0)) + (0.40 \times \text{Log}(V_{CATCHAREA})) + (0.40 \times (V_{COBBLESBA} > 10))$$

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:

$$\text{Indirect FCI} = 0.30 + (0.30 \times (V_{INLETMOD} = 0)) + (0.15 \times \text{Log}(V_{CATCHAREA})) + (0.20 \times (V_{COBBLESBA} > 10)) + (0.20 \times V_{MOUNDPRES}) + (0.20 \times (V_{SURFCRACKS} > 1)) + (0.50 \times \text{Log}(V_{MAXDEPTH}))$$

Note that ($V_{COBBLESBA} > 10$), ($V_{INLETMOD} = 0$) and ($V_{SURFCRACKS} > 1$) are all Boolean expressions, receiving a value of 1 if the expression is true, and a value of 0 otherwise.

The indirect faunal 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 functional capacity.