Geomorphic Characterization of Historical Reservoirs, Stock Ponds and Wetland Landscapes Supporting Red-legged Frogs in the Phillip Burton Wilderness, Point Reyes National Seashore

FINAL REPORT FOR THE POINT REYES NATIONAL SEASHORE

By

Laurel Collins and Joshua N. Collins, Ph.D.

March, 2007

WATERSHED SCIENCES
1128 Fresno Ave
Berkeley Ca
(510) 524-8204

Acknowledgments

We thank the Staff of the Point Reyes National Seashore and especially Brannan Ketchum for his support over the course of this study. Emily Bacon, Sumner Collins, Zack Cobb, David Cob, and Annette Dornboss provided support in the field. We appreciate the commentary of Chuck Striplen regarding Tradition Ecological Knowledge, and we thank Mark Jennings for advising our analysis of habitats for the red-legged frog, *Rana aurora draytonii*.

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1.0 Objectives

The specific objectives of this project are: (1) assess the distribution and geomorphic context of artificial impoundments (e.g., stock ponds and reservoirs) in the study area; (2) quantify the geomorphic conditions of the impoundments; (3) assess the geomorphic and ecological characteristics of impoundments considered to be critical breeding habitat for the California red-legged frog, *Rana aurora draytonii* (CRLF); and (4) describe the historical landscape and associated geomorphic processes that provided wetland habitat within the study area prior to the construction of the impoundments.

2.0 Study Area Description

2.1 Locations, Climate, and Physiography

The study area includes the Phillip Burton Wilderness north and west of Limantour Road, plus lands between the western boundary of the Wilderness and the eastern boundary of the Schooner Bay watershed (Figure 1).

Figure 1: This composite aerial image shows the boundaries of the study area. The perimeter is shown in white and the internal boundary between the Wilderness and the rest of the study area is shown in red. The Wilderness is east of the red line.

Elevation in the study area ranges from sea level to about 1300 ft at the top of Inverness ridge. Mean annual precipitation ranges from about 24 in at sea level to about 40 in along Inverness Ridge (Evens, 1988). Fog and fog-drip are important contributors to the moisture regimes throughout the study area, but especially in the higher elevations. The maritime climate at Point Reyes has temperatures in mid-winter averaging about 50°F and in mid-summer about 55°F (Evens 1998).

Inverness Ridge tends to have rounded, fairly gentle topography in its upper elevations. The side drainages leading to the coast begin as springs and seeps in gently-sloped, colluvial hollows. From their headwaters, these drainages rapidly transition into deep canyons with steep inner gorges. Debris slides, debris flows, and debris flow torrents are the dominant mass wasting processes responsible for much of the landscape dissection in this steeper terrain. In the middle portions of these watersheds, the topography becomes more rounded and gentle, with the stream valleys and their adjoining ridges broadening and decreasing in gradient toward the coast. The side ridges that separate these flatten in their lower reaches into long, broad, nearly level peninsulas. The lowermost extensions of these peninsulas border shallow esteros. The valley bottoms of these drainages also flatten in their lower reaches. In the valleys without impoundments, there is a gradual transition of wetland habitats from stream-side riparian forest and wet meadow areas into emergent freshwater marsh, intertidal brackish marsh, salt marsh and inter-tidal mudflats. In the valleys that have impoundments, there is a transition from stream-side riparian forest and wet meadows into riparian delta areas at the upper ends of the impoundments. Some valleys have multiple impoundments along their length. Numerous old stock ponds exist on springs and small tributaries in the middle and upper reaches of the drainages. These impoundments, the reservoirs and stock ponds, are the focus of this report.

There are eight main watersheds draining to the coast within the study area (Figures 1-5). For the purposes of this report, these drainages are named (from west to east): (1) Schooner View Creek that flows into Schooner Bay (Figure 1); (2) Home West Creek; (3) Home East Creek; (4) Home Ranch Creek; (5) Big Limantour Creek and (6) Little Limantour Creek that flow into Estero de Limantour; (7) Glenbrook Creek; and (8) Muddy Hollow Creek. Home Ranch, Glenbrook, and Muddy Hollow Watersheds begin at the top of Inverness Ridge and therefore yield greater amounts of runoff than the other, smaller watersheds.

Figure 2: West Home, East Home, and Home Ranch watersheds (left to right) showing mainstem dams. Pink dams are breached.

Figure 3: Big and Little Limantour watersheds (left to right) showing mainstem and major tributary dams. Pink dams are breached.

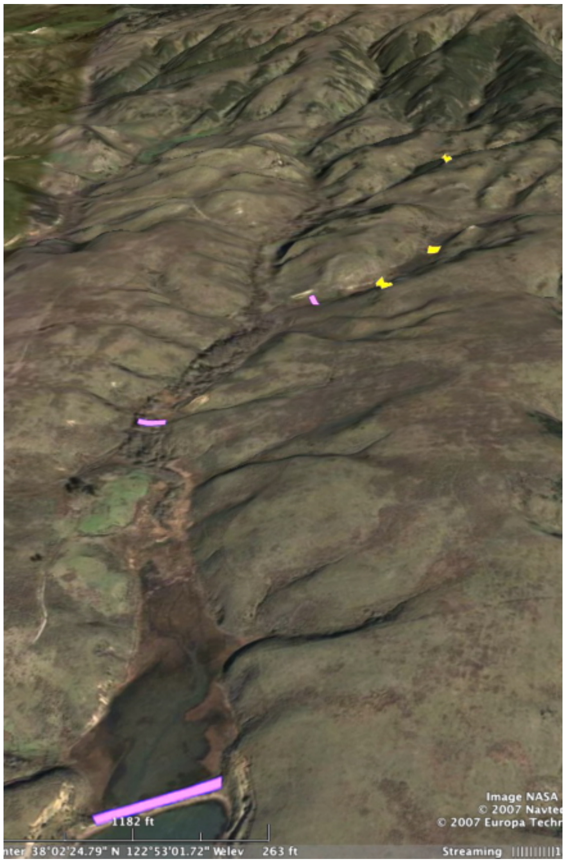


Figure 4: Glenbrook watershed showing mainstem and major tributary dams (pink dams are breached). The lowermost mainstem dam was breached in the historic January 1982 storm.

Figure 5: Muddy Hollow watershed showing mainstem dams. Pink dams are breached.

2.2 Geology

The geology in the study area has recently been described by Clark and Brabb (1997). Cretaceous-aged granodiorite extends along Inverness Ridge to about a third of the way down the peninsular spur ridges, where it intersects younger Miocene marine sedimentary rocks that overlay the granitic crustal rocks. The sedimentary rocks are along the flanks of a northwest trending structural syncline and decrease in age toward the west. There are a few minor outcroppings of Cretaceous and older metamorphic schists, gneisses, and marbles in the granodiorite near the crest of Inverness Ridge. A narrow band of clay-rich sandstone of the Laird formation, which is the oldest sedimentary rock overlaying the granitic batholith, crosses the study area at about mid-watershed elevation. A broader band of porcelanites and cherts of the Monterey Formation overlay the Laird Formation. The Monterey Formation occurs throughout the middle reaches of the watersheds. A narrow band of clay-rich sandstone of the Santa Margarita Formation gives way at the lowermost elevations to the Purisima Formation, the youngest sedimentary formation in the study area. The Purisima Formation consists of mudstones, siltstones and sandstones. It comprises the lowermost reaches of the peninsular ridges that separate the esteros. The larger valleys adjoining the esteros are filled with Holocene and Pleistocene alluvium that usually extends into the tributary canyons as narrow terraces. In many of the steeper canyons, the alluvium is intermixed with colluvium and debris flow material.

The entire Point Reyes Peninsula has been influenced by a long and complex history of tectonic uplift and marine submergence. It is bounded about 1.5 miles east of the study area by the right-lateral strike-slip trace of the San Andreas Fault. It is bounded to the west by the Point Reyes thrust fault that probably accounts for much of the ongoing tectonic uplift. Clark and Brabb (1997) suggest that the elevated sea terraces along with ancient alluvial and coastal dune deposits indicate that the Peninsula has been rising throughout the Quaternary Period. They report that sea-level rise has totaled 394 ft during the last 18,000 years, putting the ancient coastline almost 31 miles west of its present position. Uplift is a continuing process. Grove et al (2005) report local uplift rates between 1 and 2 mm per year, based on the ages of marine terraces.

Since the beginning of the Holocene, the Pacific Ocean has been rising and invading the lower reaches of the main watersheds, creating Drakes Bay and the other esteros. As the ocean continues to rise, the esteros will tend to move inland. During the next 50-100 years, global warming and accelerated sea level rise could move the boundaries between fluvial and tidal conditions hundreds of feet upstream within the low-gradient valleys of the major watersheds.

2.3 Vegetation

The study area has a great diversity of vegetation. This brief account is only meant to characterize the communities that dominate the major geomorphic units of the watersheds.

The granitic ridges are dominated by coastal scrub and forests of Bishop pine (*Pinus muricata*). The coastal scrub includes Manzanita (*Arctostaphylos* spp), currant (*Ribes* spp.), coyote brush (*Baccharis pilularis*), buckbrush and blue blossom (*Ceanothus* spp.), lupin (*Lupinus* spp.), bracken fern (*Pteridium aquilinum*), blackberry and raspberry (*Rubus* spp), and sage (*Salvia* spp.). The understory of the Bishop Pine forest includes huckleberry (*Vaccinium* spp), salal (*Gaultheria shallon*), and sword fern (*Polystichum munitum*).

At lower elevations, the wetter, northeast-facing slopes support narrow bands of mixed hardwoods and broader areas of Douglas fir (*Pseudotsuga menziesii*). The overstory of the hardwood forest includes live oak (*Quercus agrifolia*), bay (*Umbellularia californica*), and buckeye (*Aesculus californica*). The understory includes blackberry (*Rubus* spp), poison oak (*Rhus diversiloba*), and a variety of groundcover forbs. The drier, southwest-facing slopes support coastal scrub.

The coastal scrub community transitions into a mixture of coastal prairie and coastal rangeland across the tops of the broad peninsular ridges between the esteros and along the edges of the valley bottoms. The areas of the of the peninsular ridges that have been retired from grazing appear to have a higher proportion of northern coastal prairie, including perennial bunch grasses, sod-forming grasses, Douglas iris (*Iris douglasii*), raspberry, and bracken fern, than the grazed areas that have greater abundance of invasive non-native species such as wild oats (*Avena* spp.), and velvetgrass (*Holcus lanatus*).

The riparian forest overstory along the major stream corridors and on the deltas at the upstream margins of the larger reservoirs is dominated by red alder (*Alnus rubra*) and willow (*Salix* spp), with minor amounts of buckeye and elderberry (*Sambucus* spp.). The understory tends to be densely vegetated with blackberry or Himalaya berry (*Rubus procerus*), salmon berry (*Rubus spectabilis*), stinging nettle (*Urtica dioica*), poison oak, and other herbaceous growth.

There are many kinds of wetlands within the study area and each has a characteristic flora. Freshwater slope wetlands (seeps and springs) exist at the bottoms of colluvial hollows, along the toes of alluvial fans, and along the bases of wet hillslopes. These wetlands tend to be dominated by tall *Carex and Juncus*, with undercover of cinquefoil (*Potentilla* spp), raspberry, and grasses. Emergent wetlands at the edges of perennial impoundments and reservoirs tend to be dominated by cattails (*Typha latifolia* and *T. angustifolia*), bulrushes (*Scirpus acutus* and *S. californicus*), and tall *Carex*. The littoral zone of seasonal impoundments tends to be dominated by spikerush (*Eleocharus* spp), small rushes (*Juncus* spp), pennyroyal (*Mentha pulegium*), and other grasses. The littoral zone of perennial impoundments tends to be dominated by American pennywort (*Hydocotyle Americana)*, water celery and water parsley (*Oenanthe* spp.), celery, and pond weeds (*Potamogeton spp.)*. Some impoundments become covered with duck weed (*Lemna minor*) or water fern (*Azolla* spp.) during summer months. The ecotone from valley bottom to intertidal marsh supports abundant salt grass (*Distichlis spicata*), and brass buttons, (*Cotula coronopifolia*), whereas the salt marshes are dominated by pickleweed (*Salicornia virginica*).

These plant communities tend to form very dense cover throughout most of the study area. Places of thin cover with some exposed bare ground are restricted to rock outcrops, roads and trails, horse paddocks and cattle corrals, scattered patches of thin soil on the tops of the peninsular ridges that border the esteros, and along the exposed shorelines of impoundments and reservoirs during periods of low water. In most places the plant cover is dense and multi-layered, offering at least minimal cover for ground-dwelling wildlife.

2.4 Land Use

There is archeological evidence that people have inhabited the Point Reyes Peninsula for the past several thousand years (Clark and Brabb, 1998). The indigenous people were mostly gone from the area before Euroamerican land use began (Livingston 1994). The interim period must have been characterized by gradual secondary ecological succession in response to a total lack of human intervention. With the demise of indigenous land management, especially the cessation of fire as a vegetation management tool, the coastal scrub community and forests probably expanded into the coastal prairie and hillside grasslands.

Modern land use in the study area has principally been dairy and cattle ranching. Cattle grazing probably began in the second decade of the nineteenth century, when feral missionary cattle reached Point Reyes, but did not achieve prominence until the middle 1800s (Livingston 1994). By 1900, five dairies were operating within the study area, from the top of Inverness Ridge (e.g., Oporto and Sunnyside dairies) to the bottoms of the main valleys (e.g., Muddy Hollow and Glenbrook dairies). Some valleys and ridge tops were intensively plowed and sowed with pasture grasses. Wharfs were built to ship dairy goods to market. Artichoke farming was conducted on some of the peninsular ridge lands between Limantour Estero and Home Bay. A plant nursery was created in the middle of Muddy Hollow watershed. Woodcutting was conducted in the forested ridges. Ranch roads were graded and re-graded throughout the study area. Springs and stock ponds were developed for people and cattle. Larger reservoirs were created in preparation for residential development. Native predators were hunted into extirpation and feral deer and goats were added. These activities in aggregate kept the landscape in a continuing state of ecological disturbance for nearly 200 years. Early photos of the valleys and hillsides during the period of peak agricultural activity show extensive gullies, severely grazed hillsides, dewatered valleys, incised channels, greatly restricted riparian zones, denuded areas where cattle concentrated, and well-used roadways that crisscrossed the landscape.

Large scale land use changes began in the study area during the early 1960s, as the National Seashore was being established. Most of the Seashore lands were acquired between 1962 and the late 1970s (Hart 1979, Livingston 1994). Intensive grazing was restricted from the Phillip Burton Wilderness Area soon after it was established in 1976. The boundary was fenced and most cattle were removed from the designated Wilderness, including most of the study area.

The suppression of fire and the lack of grazing in the Wilderness allowed fuel to accumulate to unprecedented levels. In 1995, intense wildfire burned a large portion of the study area, including the entire watersheds of Muddy Hollow Creek and Glenbrook Creek, the eastern peninsula of Limantour Estero, and the middle and upper drainages of Limantour Creek. Natural recovery of vegetation has been rapid throughout the burned portion of the study area.

Much of the land outside of the Wilderness Area continues to be grazed. The study area includes a portion of these grazed lands (see Figure 1).

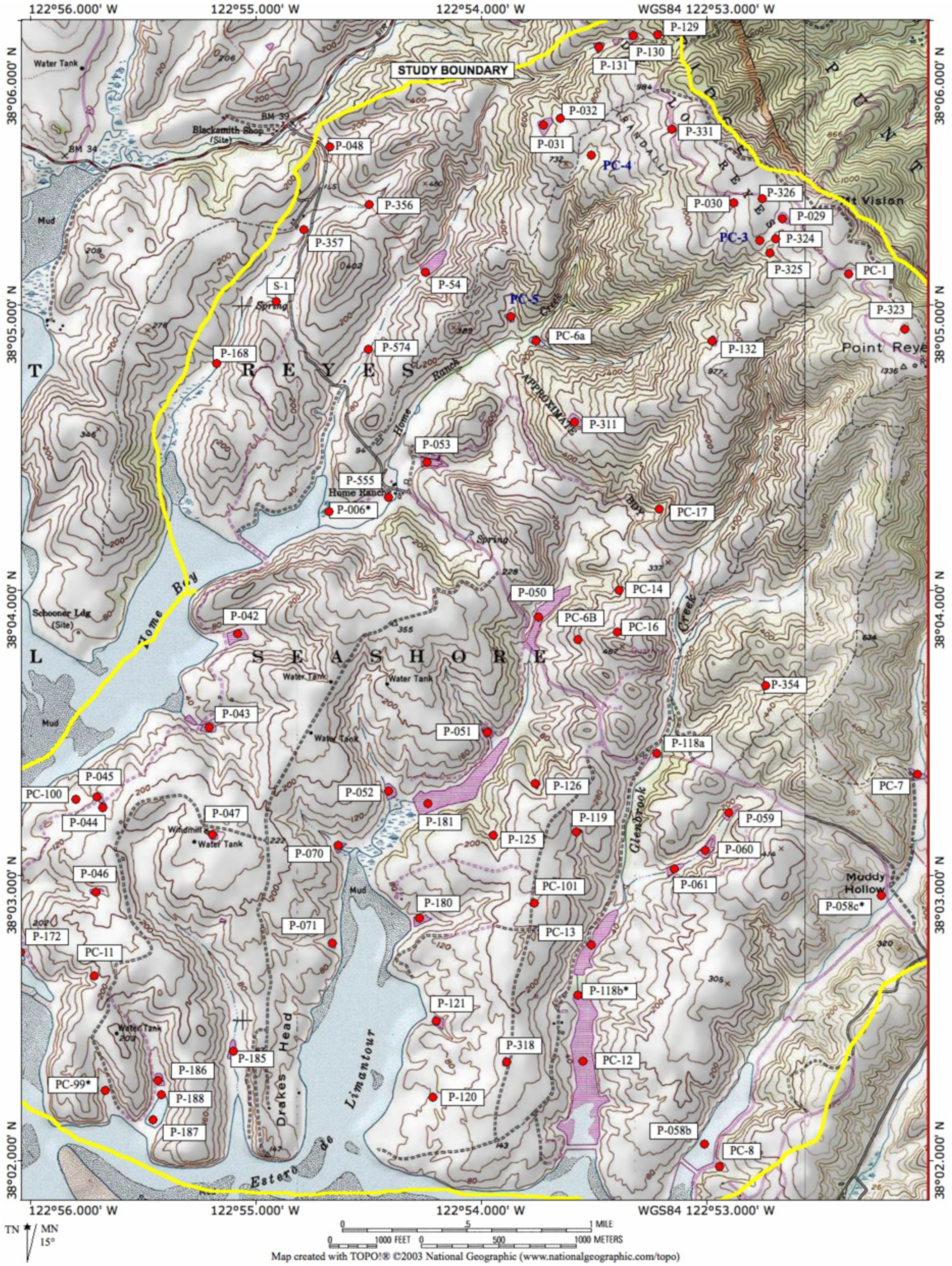
3.0 Classification of Study Sites

3.1 Site Distribution

All reservoirs, stock ponds, spring boxes, and other man-made lentic features within the study area are referred to as impoundments. These impoundments, plus natural features such as unimproved seeps and springs, depressional wetlands, and stream pools that were examined in this study are collectively referred to as study sites.

All the study sites were identified on a 1:24,000 scale topographic map of Point Reyes National Seashore and its vicinity (Figure 6). The sites were located based on earlier surveys of CRLF (Fellers and Guscio 2002, Fellers and Osbourn 2004), review of historical and recent maps and aerial photography that were provided through the archives of the Point Reyes National Seashore, and extensive field surveys conducted for this study. All the sites surveyed by Fellers and Guscio (2002) and Fellers and Osbourn (2004) within the study area, plus all but two additional sites identified through the review of aerial imagery were visited in the field. The site labels used in the previous CRLF surveys (Fellers and Guscio 2002, Fellers and Osbourn 2004) were retained, and new unique labels (e.g., PC-1, PC-2, etc) were given to the additional sites.

The fieldwork proceeded from the sites at higher elevations along Inverness Ridge downslope through the tributary drainages, along the peninsular ridges and through the valley bottoms of the eight major watersheds draining to esteros of Drakes Bay. A total of 72 sites were mapped and 70 sites were visited during the study period November 2004 to January 2006 (Figure 6). Two sites that were mapped but not visited were inaccessible due to dense re-growth of scrub communities and Bishop pine forest following the Mount Vision Fire of 1995.



Map created with TOPO!® ©2003 National Geographic (www.nationalgeographic.com/topo)

Figure 6: Locations of 72 study sites from a 1:24,000 scale topographic quadrangle (USGS 1955; stippled pink areas were photo-revised in 1977). Yellow lines delineate the boundary of the study area. The hydrography differs in some locales from what is indicated by this base map. For example, impoundments P-061 and PC-12 have been breached since the 1977 photo revisions. Sites with an * are natural sites on floodplains or terraces.

3.2 Impoundment Classification Based on Geomorphic Setting

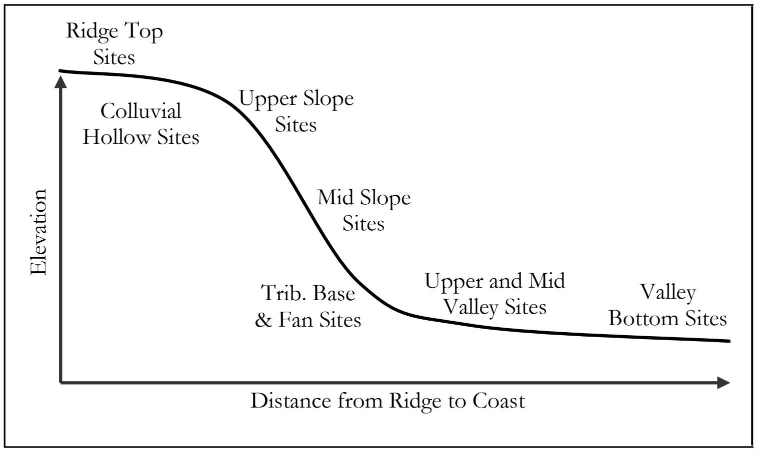


Figure 7: Conceptual model of seven hydro-geomorphic settings along a typical watershed profile within the study area. The settings are arranged from the top of the watershed along Inverness Ridge to the bottom of the watershed at Drakes Bay.

This characterization of impoundments assumes that their distribution, form, and longevity depend mainly on geomorphological processes that vary predictably with elevation and distance upstream from Drakes Bay. For example, the surface area, depth, and shape of impoundments vary with the slope and breadth of valleys, which in turn vary with position along the drainage network of any watershed in the study area. Based on these considerations, seven geomorphic settings were identified (Figure 7).

3.2.1 *Ridge Top impoundments* tend to be small because they have small catchments for runoff. They exist at the heads of drainages and were intended to serve as stock ponds. They are more dependent on direct precipitation than other types of impoundments.

3.2.2 *Colluvial Hollow impoundments* occupy zero-order basins (i.e., unchannelized hollows above a channel head) in the headwater reaches of watersheds. In this setting, Low dams and small excavations were used to impound runoff from small catchments as stock ponds.

3.2.3 *Upper Slope impoundments* are located on first-order channels or on the uppermost reaches of second-order channels, where drainage networks begin to steepen. The dams tend to be larger than the dams in colluvial hollows because they have larger drainage areas. They seldom have other sites above them. They always have dams across natural low-order channels. They were apparently built as stock ponds.

3.2.4 *Mid Slope settings* encompass the second-order channels or the upper reaches of third-order channels in the steepest sections of the drainage networks. They are affected by mass wasting processes on adjacent side slopes. There are no Mid Slope impoundments in the study area, probably because this setting is less accessible to stock animals and very difficult to access with construction equipment.

3.2.5 *Tributary Base and Fan* impoundments are located where major tributaries enter mainstem valleys. This setting in some cases features an alluvial fan. Sites in this setting can be affected by upstream mass wasting and are commonly downstream of upper slope sites. The impoundments always have dams, and are larger than most other types of impoundments that occur further upstream. Some were apparently built as reservoirs as well as stock ponds.

3.2.6 *Constructed Upper and Mid Valley* impoundments occupy the middle or upper reaches of the mainstem valleys. They tend to receive large enough amounts of bedload from upstream to have forested deltas along their upstream margins. They are commonly downstream of other impoundments. They can be severely impacted by floods and the failure of dams upstream. They always have dams, are larger than most other impoundments that occur further upstream, and were probably built as reservoirs as well as stock ponds. Since they are larger that other impoundments, they can be more exposed to wind, and therefore more susceptible to wind-wave erosion.

3.2.7 *Valley Bottom* impoundments exist at the historical transitions from fluvial to tidal conditions at the bottoms of mainstem valleys. They tend to receive large enough amounts of bedload to form deltas with dense riparian forests at the points of inflow. In some cases, the dams can be subject to estuarine wave erosion on their downstream sides as well as wind-wave erosion on their upstream sides. They were all built as reservoirs as well as stock ponds. The largest impoundments exist in this setting.

3.3 Impoundment Classification Based on Dam Construction

The impoundments were classified by construction type so that possible relationships among construction, geomorphic setting, and site condition could be investigated.

Impoundments have been constructed in the study area to provide water for domestic use, agriculture, wildlife, and recreation. All the impoundments were constructed before the Point Reyes National Seashore was established. The impoundments for recreation were constructed in anticipation of residential development, and are the largest in the study area. None of the impoundments within the Wilderness have been maintained since the Wilderness was established in 1976.

It seems unlikely that many of the impoundments were rigorously engineered. They were constructed by ranchers and dairy operators with limited equipment. Intensive maintenance was not desirable but neither were large expenditures for design and construction.

3.3.1 *Small Excavations with Minimal or No Dams* can be created anywhere but are most common on the Ridge Tops and at the higher elevation Colluvial Hollows and Upper Slope geomorphic settings. A simple basin is excavated into a seep or slope wetland, and the extracted material is side cast rather than used to construct a dam. These impoundments typically lack any kind of constructed drainage feature. Drainage is affected by seepage and evapotranspiration.

3.3.2 *Moderate Excavations with Dams* are created by excavating an area round a small channel and using the excavated material to form a dam and the downstream boundary of the excavation. These kinds of impoundments are sometimes referred to “balanced cut and fill” (Wakita and Lind 2003). The excavations usually extend deeper than the base of the dam and intercept groundwater. If the dam is breached, a small impoundment tends to remain. This construction approach is commonly used in a variety of geomorphic settings: Colluvial Hollows, Upper Slopes, Tributaries and Alluvial Fans, and Upper Valleys. Most of the dams are notched at one end to create a simple spillway. Some spillway notches were excavated into adjoining hillsides or bedrock. Notches constructed in bedrock tend to be less erodable. A few of the larger “balanced cut and fill” impoundments have culverts or other drain pipes in addition to a spillway notch. The invert elevations of drainage pipes and spillways are usually the same.

3.3.3 *Minimal Excavations with Dams* form the largest impoundments in the study area. They are restricted to broader Mid Valley or Valley Bottom settings. Although there is little excavation, the dams span the valleys. The adjacent hillsides are quarried for the material used to build the dams, which usually support a roadway or trail. The spillway notches are almost always cut into an adjoining hillside. In a few cases, the spillway leads to a ditch that restricts outflow and runoff to one side of the downstream valley. Some of the larger dams were raised and widened after their initial construction. A borrow pit is always associated with this kind of impoundment.

3.4 Natural Hillside Sites

The natural sites found in the study area at this time include persistent remnants of historical topographic depressions on ridge tops, transient depressions relating to landsliding on steep hillsides, and shallow depressions associated with emerging groundwater at the base of some hillsides along valley bottoms.

Sag Ponds are depressional wetlands or small lakes that form in the topographic lows created by seismic processes, usually along active fault traces. While there are sag ponds elsewhere within the greater Point Reyes area, especially along the San Andreas fault zone through Olema Valley, we are not aware of any sag ponds in the study area.

3.4.1 *Topographic Depressional Wetlands* are located in “saddles” or small basins on broad ridge lines. They have a hardpan or bedrock substrate that inhibits infiltration and allows rainfall to accumulate in very shallow, ephemeral pools that desiccate during the dry season. Two examples are sites P-323 and PC-101 on Inverness Ridge and the Limantour Headlands, respectively.

3.4.2 *Landslide Depressional Wetlands* form where groundwater emerges along the scarps of rotational slumps. Such features are most common in the Upper Slope and Mid Slope settings of the study area. Some of them can be perennially wet, but the ones visited during this study do not include standing water. Most of these wet depressions disappear as the slumps erode or move downslope. At Lake Ranch, south of the study area, natural lakes have formed in association with very large ancient landslides. Similar features do not exist in the study area.

3.4.3 *Seeps and springs* can be found at various places below the ridge lines, but are most common where hillsides intersect valley bottoms. Some of these features fill shallow, linear depressions during the rainy season. An example is site P-058c in the Muddy Hollow watershed.

3.5 Natural Floodplain Sites

Some natural sites are associated with dynamic fluvial processes operating on active floodplains and low terraces within the study area. The most common features are tree fall pools in riparian forests, relatively large in-stream pools, and remnants of abandoned channels that fill with rainwater or groundwater during the wet season.

3.5.1 *Tree Fall Pools* form under the uprooted and tilted root balls of large fallen alders or other riparian trees on deltas at the upstream ends of the larger Upper Valley and Valley Bottom impoundments. These pools are small (i.e., smaller than the associated root balls) and they probably persist for a few years or less. They can be common following large storms that cause much tree throw. None of these features have been mapped, but they can be observed on the deltas at sites P-050 and P-054.

3.5.2 *In-stream Pools* are depressions in the beds of the gaining reaches of streams that develop lentic characteristics during the dry season by impounding base flow. Such features come and go along a channel due to its migration, incision, or aggradation. Relatively persistent pools exist in more stable channels. A few in-stream pools have been mapped as CRLH habitat. Site P-357 is a scour pool at the downstream end of a culvert under Home Ranch Road.

3.5.3 *Remnant Channel Pools* are portions of abandoned stream beds on floodplains or low terraces that fill with rainwater or groundwater during the wet season. They are not uncommon in the flood-prone areas of valley bottoms, especially in the broad transition zones from flood-prone valley bottoms to intertidal marshes. Sub-adult CRLF were observed in remnant channel pools near site P-006 (at the bottom of Home Ranch valley). There are also examples of remnant channel pools on the floodplain upstream of site P-356, an Upper Valley impoundment known to support CRLF.

3.6 Natural Supra-tidal Features

Sub-adult CRLF were observed in sites near the maximum high tide contour that are therefore occasionally subject to tidal action. These sites include coastal lagoons behind barrier berms and in-stream pools near the head-of-tide in small estuarine streams.

3.6.1 *Lagoons* form behind wave-built berms of sand and wrack above the usual high tide line at the mouths of small watersheds along the shorelines of some esteros. Some lagoons have areas of low salinity suitable for CRLF. The berms are occasionally breached by storm waves or flood flows and then are naturally reformed with wave-deposited sand and other materials. An example is site P-187 east of the terminus of Sunset Trail.

3.6.2 *Estuarine Stream Pools* are in-stream pools of low salinity subject to occasional tidal action. They are most common in the channels that drain lagoons. Sub-adult CRLF were observed in estuarine pools below site P-187 and near site P-006.

3.7 Study Site Age

The minimum ages of the study sites were estimated from aerial imagery and maps of various vintages. Due to long gaps in time between maps and image sets, and due to differences in the extent to which they encompass the study area, the estimates of site were too inexact for site-specific geomorphic assessments. For example, they could not be used to estimates rates of geomorphic processes, such as infilling or dam erosion. The estimates of minimum site ages are presented in Appendix 1.

3.8 Results and Discussion of Site Classification

3.8.1 *Distribution of Sites among the Geomorphic Settings*

There are 25 Colluvial Hollow sites, 14 Valley Bottom sites, 10 Upper Valley sites, 10 sites in the Tributary Base and Alluvial Fan setting, 6 Upper Slope sites, and 5 sites on Ridge Tops. The abundance of Colluvial Hollow sites probably reflects the relative ease with which seeps and springs in this setting can be accessed by stock animals and modified into stock ponds, plus the close proximity of this setting to many of the historical dairies in the study area. The relative abundance of sites in the mainstem valleys and at the base of major tributaries reflects the more recent creation of reservoirs as part of land developments that were abandoned when the

Wilderness was established. There are few Upper Slope sites and no Mid Slope sites probably because access to these settings with construction and maintenance equipment is very difficult. Most of the Ridge Top sites are natural depressional wetlands in topographic lows.

3.8.2 *Relationship between Drainage Area and Geomorphic Setting*

The watersheds of many sites can be separated into two parts. A site's historical or "natural" watershed includes all the areas upstream of the site that drain to it. Its current or "modified" watershed does not include any area of its historical watershed that now drains to another site.

Most of the impoundments (especially the smaller ones) probably fill and spill with the first major rains each year. The historical watershed of a site therefore contributes to the site's water supply and suspended sediment supply. Only the largest impoundments are likely to attenuate downstream flood peaks and downstream supplies of suspended sediment. Every site tends to trap all the bedload it receives, however, unless the site gets breached. Therefore, only the modified drainage area of a site contributes to its bedload supply.

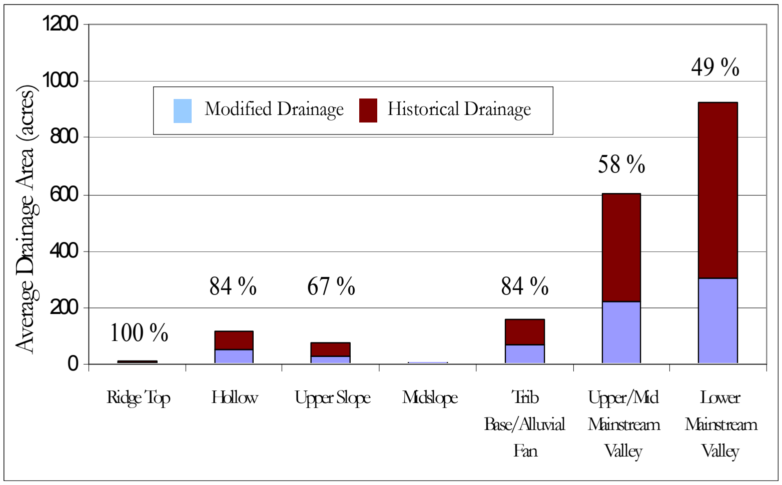


Figure 8: Average drainage area in relation to geomorphic setting. The historical drainage area of an impoundment includes all of its upstream areas. The modified drainage area excludes the portions of the historical area that drain to other impoundments. The numbers above the bars represent the modified drainage areas as percentages of the historical drainage areas.

As expected, based on the dendritic form of the drainage networks, the sizes of historical and modified watersheds tend to increase geometrically downstream from the Ridge Top settings to the Valley Bottom settings near sea level (Figure 8).

3.8.3 *Relationship between In-filling and Geomorphic Setting*

For the uppermost setting (i.e., Ridge Tops), the modified drainage areas tend to be too small and not steep enough to generate much sediment, although they can comprise large percentages of the historical drainage areas (see Figure 8 above). Ridge Top sites therefore tend not to fill in. This helps explain why these impoundments are among the oldest in the study area.

The Colluvial Hollows and Upper Slope sites have relatively small modified drainage areas. The catchments for colluvial hollows lack channels and therefore receive minimal sediment due to fluvial processes. Most Upper Slope sites are served by short channels in steep catchments. Colluvial Hollows and Upper Slope sites tend to be associated with hillslope processes, such as soil creep and shallow landslides that can generate abundant sediment. These sites tend to have prograding shorelines along their sides and upstream margins. There were no Mid Slope sites in the study area, probably because the Mid Slope setting is very difficult to access.

Some impoundments have lost a significant amount of their original volumes due to in-filling with bedload from upstream sources and/or in-situ production and accumulation of plant material. The amount of bedload in-filling relates to geomorphic setting (Figure 9).

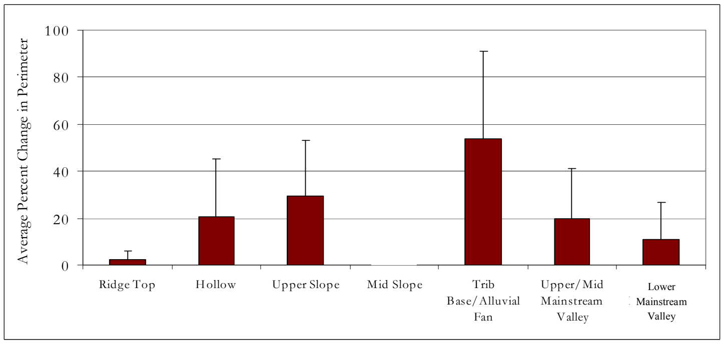


Figure 9: Relationship between the geomorphic setting of a site and its tendency to fill-in with sediment from upstream sources, as indicated by its maximum percent decrease in size as measured in aerial imagery. Breached sites were excluded from this analysis.

Tributary Bases and Alluvial Fans tend to receive large amounts of bedload from the steep Mid Slope areas, where landslides are common. Since the channel downstream of a dam is deprived of sediment (i.e., the sediment needed to maintain the channel's hydraulic geometry is trapped behind the dam), the channel tends to incise. Much of the sediment from the incised channel tends to be deposited in the next downstream impoundment.

The impoundments in the Tributary Base and Alluvial Fan settings are not especially large, however (see Figure 10 below). When impoundment size and upstream sediment sources are considered together, the impoundments at the Tributary Base and Alluvial Fan settings seem most likely to experience in-filling, even if the impoundments above them do not fail. As expected, the impoundments constructed on fans or at tributary confluences tend to be more in-filled than impoundments in any other settings (Figure 9).

The sites that occur in the valley settings (i.e., Upper Valley sites and Valley Bottom sites) receive enough sediment to create forested deltas, but the amount of in-filling is small compared to the large size of these impoundments. A few sites at Valley Bottom settings, such as PC-13, which is a floodplain site below a breached dam, have large modified drainage areas due to their downstream locations (i.e., they are far-removed from upstream impoundments that function as sediment traps. These impoundments therefore have high potential for in-filling (Figure 9).

3.8.4 *Relationship between Geomorphic Setting and Site Size*

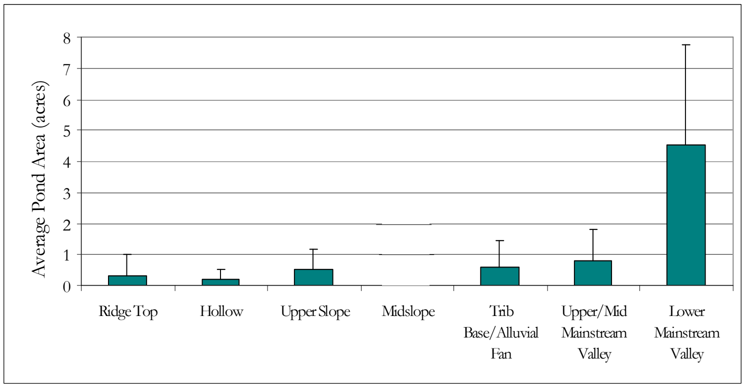


Figure 10: Relationship between the sizes (surface areas) of impoundments and their geomorphic setting.

The majority of the impoundments in the study area are rather small, less than one acre in overall surface area (Figure 10). This probably reflects the intended use of most sites as stock ponds for small historical dairies and farms that were distributed throughout the watersheds.

Impoundment size increases slightly downstream from the

Ridge Top setting to Upper Valley setting (Figure 10). A few of the Upper Valley sites are too large to have been designed just as stock ponds, and were probably designed also for recreation and water supply. Impoundment size increases abruptly in the Valley Bottom setting, where the larger reservoirs were built for recreation. The large surface area of these impoundments can be explained, in part, by the broad and gently sloping valleys that they inundate.

3.8.5 *Relationship between Geomorphic Setting and Dam Construction*

Geomorphic setting strongly influences site construction methods (Figure 11). There are no sites in the very steep Mid Slope settings, where access with construction equipment is most difficult. Ridge Top sites were only constructed by simple excavation. Almost all Colluvial Hollow constructions were either simple excavations or low dams were built using the excavated material. Dams get larger and more prevalent downstream from the Upper Slope setting. Most sites in the Valley Bottom setting have been constructed with large dams and no excavation. Material queried from adjacent hillsides was used to cover dam faces.

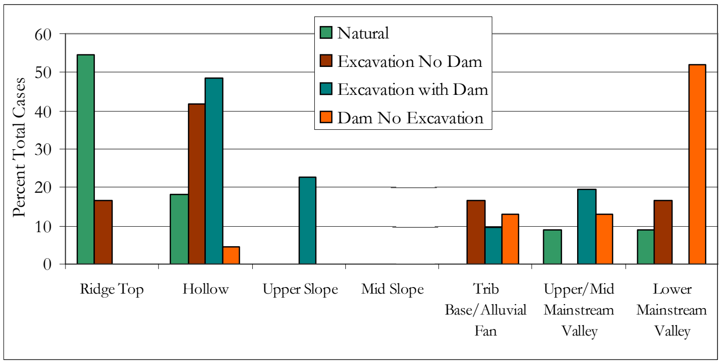


Figure 11: Relationship between the geomorphic setting of an impoundment and how it was constructed.

4.0. Geomorphic Assessments of Site Condition

The geomorphic assessments of study sites were guided by a conceptual framework that integrates on-site conditions with upstream and downstream conditions (Figure 12). The framework follows from the site classification results presented in Section 3.0 above. In essence, the model suggests that the geomorphic setting of a site influences a broad suite of hydro-geomorphic processes that account for the site's condition, its threat to downstream sites, and the threat that is represented by upstream sites. It further suggests that on-site assessments should focus on the conditions of dams and spillways.

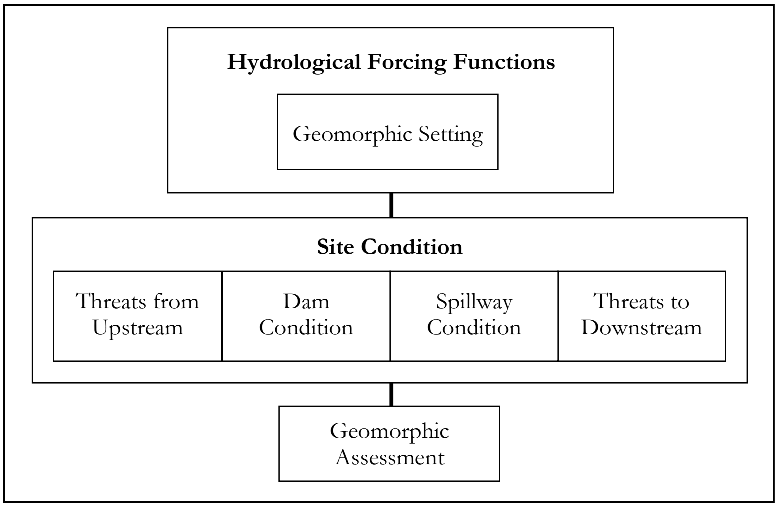


Figure 12: Conceptual framework for the geomorphic assessment of impoundment and other study sites.

Based on this framework, indicators of geomorphic condition were developed. Each indicator was binned into three or more levels representing the full range of condition observed in the field. The levels of each indicator were assigned numerical values comprising a simple arithmetic scale from low to high. The lowest levels were represented by non-zero values to prevent "division by zero" problems in the indices described below. The indicators evolved somewhat during the assessments, requiring some sites to be revisited and reassessed. The final suite of indicators used to assess the geomorphic condition of each study site is described in Appendix 2.

All survey data were entered into a master spreadsheet and subjected to basic quality control and assurance procedures to make sure all appropriate indicators were evaluated for each site and that all the evaluations were within acceptable ranges. The spreadsheet for the geomorphic survey is available from Watershed Sciences and has been provided to the Point Reyes National Seashore as an electronic file. The field notes from the survey were summarized into brief site descriptions, which are provided as Appendix 3.

4.1 Dam Condition Index

The dam condition index combines independent measures of dam erosion with a separate measure of minimum dam width. The four components of dam erosion for each site are equally weighted as percentages of their maximum values for all sites. The sum of these components is scaled by the minimum dam width score for the site, which increases as the dam narrows. Larger index values are associated with severe erosion of narrow dams.

$$\boxed{\begin{array}{c}\text{Dam}\\ \text{Condition}\\ \text{Index}\end{array}} = \boxed{\text{Dam Width Score}} \ \mathrm{X} \ \boxed{\begin{array}{ll} & \text{Dam Seepage Score}\\ + & \text{Dam Face Erosion Score}\\ + & \text{Interior Wave Erosion Score}\\ + & \text{Exterior Wave Erosion Score}\end{array}}$$

4.2 Spillway Condition Index

The spillway condition index for each site is simply the percent maximum spillway condition score for all sites. The index increases in numerical value as spillway condition decreases.

$$\boxed{\begin{array}{c}\text{Spillway}\\ \text{Condition Index}\end{array}} = \boxed{\dfrac{\text{Site Spillway Class}}{\text{Max. Spillway Class}}}$$

4.3 Site Sustainability Index

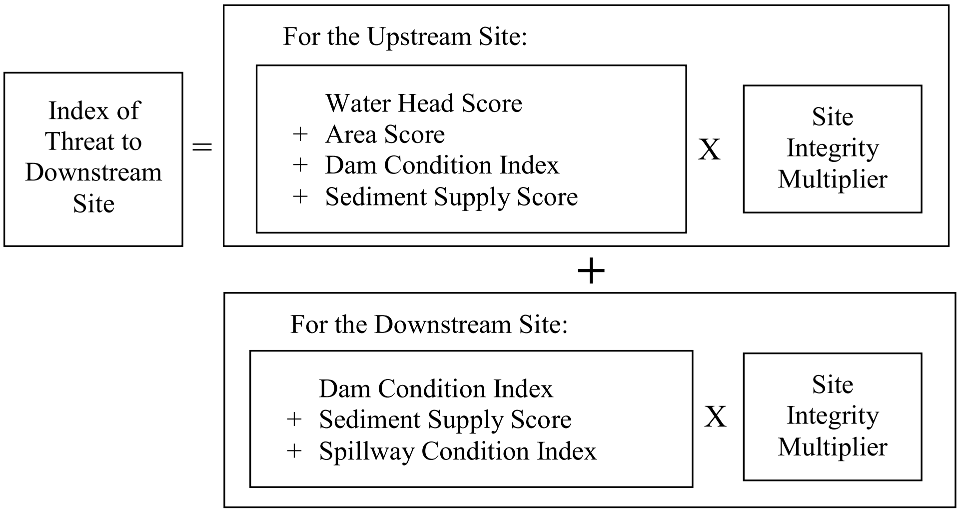
The site sustainability index is simply the inverse of the product of the breach hazard multiplier times the sum of the dam and spillway condition indices. The breach hazard multiplier accounts for breach status. Fully breached sites have the lowest values. If these sites are excluded, then sites where breaching is eminent have the lowest values. The highest values pertain to sites that are least likely to be breached.

4.4

$$\boxed{\begin{array}{c}\text{Site Sustainability}\\ \text{Index}\end{array}} = \boxed{\begin{array}{c}\text{Dam Condition Index}\\ +\\ \text{Spillway Condition Index}\end{array}} \ \mathrm{X} \ \boxed{\begin{array}{c}\text{Site}\\ \text{Integrity}\\ \text{Multiplier}\end{array}}$$

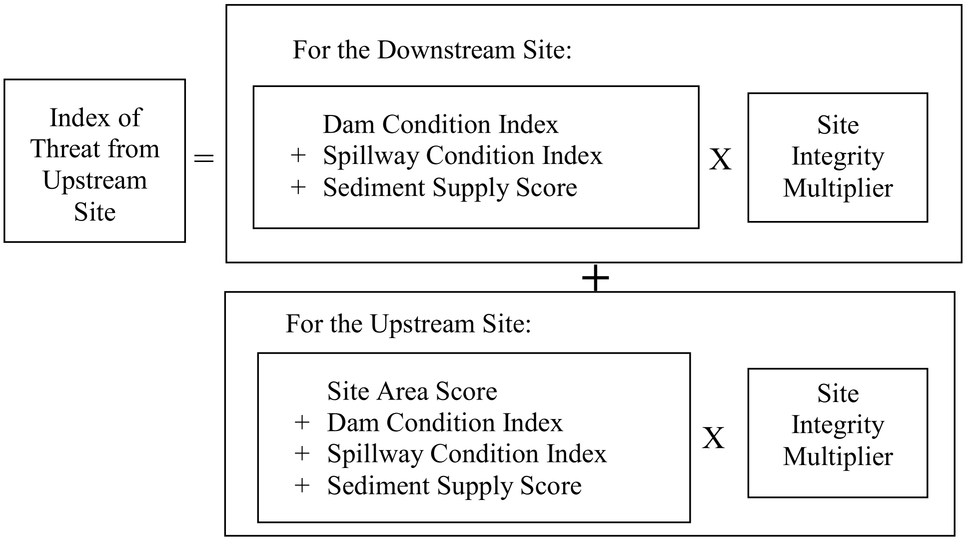
Index of Threat to Downstream Sites

This index pertains to sites that are within 1000 ft upstream of another site. It rates the upstream site for the likelihood of it breaching and the likely magnitude of the effects of its breach on the downstream site. The index is greater for large failing sites that are upstream of failing sites.



4.5 Index of Threat from Upstream Sites

This index pertains to sites that are within 1000 ft downstream of another site. It rates the downstream site for the likelihood of an upstream site breaching, and the likely magnitude of its response to the upstream breach. The index is greater for failing sites that are downstream of large failing sites.



4.6 Results and Discussion of the Geomorphic Characterization of Impoundments

4.6.1 *Site Damage Mechanisms*

There are many ways that impoundments in the study area have been damaged or destroyed. In every case, the dame and destruction is due to partial or complete dam failure. Piecing together the sequence of events for all the different contributing factors in every case of a failing dam is not possible. There can be multiple and interacting causes. Table 1 presents the geomorphic factors and processes observed in the field that could affect dam failure. Spillway incision, seepage on the exterior face of the dam, and overtopping due to clogged spillways or drainage pipes are the leading causes of dam failure.

Table 1: Factors and processes of site degradation or failure.

Factors and Processes Affecting Condition of Dam Face	Animal burrows, plant roots, inadequate compaction, and/or inappropriate fill materials lead to chronic seepage and slumping of exterior dam face.
	Cattle trammeling leads to gullying and erosion of exterior and/or interior dam face.
	Overtopping of dam erodes its top surface and exterior face.
	Gullying at outfalls of drainage culverts or pipes leads to erosion of exterior dam face.
	Collapse of drainage culverts or pipes causes dam top to sag and promotes overtopping.
	Drainage culverts or pipes are clogged causing notched spillway incision and/or dam overtopping.
	Channel downstream of dam incises upstream into dam base.
	Wind-generated waves erode exterior dam face (see photo, page 41).
	Waves at high tide are eroding exterior dam base.
	Seismic event triggers catastrophic dam shaking or liquefaction.
Factors and Processes Affecting Overtopping	Spillway and other drainage structures are undersized.
	Spillway and/or other drainage structures become clogged.
	There is a sudden and catastrophic failure of an upstream dam.
Factors and Processes Affecting Spillway Condition	Vegetation or excessive sedimentation reduces spillway capacity.
	Downstream channel cuts headward into spillway (see photo, page 41).
	Excessive flow through spillway causes its incision.
Other Factors and Processes Affecting Site Capacity	Upstream flow discontinues.
	Impoundment fills with bedload and/or hillside colluvium.
	Impoundment fills with autochthanous organic debris.
	Ground water level drops below basin of breached dam.

Figure 13 to the right presents the sustainability scores for all sites. The scores increase from the fully breached sites to the sites least likely to be breached. Sites that are in the process of being breached are termed “partially breached.” These are the least sustainable sites at this time, given their deteriorating conditions. The “threatened” are not yet being breached but are subject to erosion processes that make at least partial breaching almost inevitable. The “stable” sites, including all the natural sites, are not in any risk of being breached in the foreseeable future.

Of the 72 sites assessed in this study, only 13 are natural. Of the 59 impoundments, 26 are stable, 12 are threatened, 7 are partially breached, and 14 are fully breached.

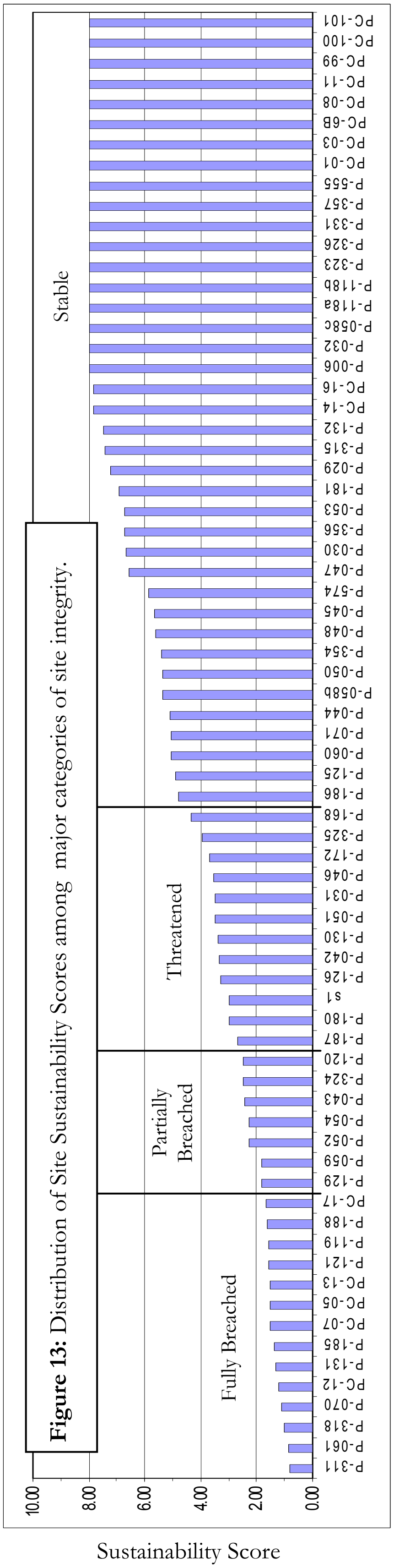


Figure 13: Distribution of Site Sustainability Scores among major categories of site integrity.

4.6.2 *Relationship of site sustainability to breach mechanism and geomorphic setting*

Table 2 on the next page summarizes the relationships between site sustainability, the processes that tend to erode dams and spillways, and geomorphic setting. Breaching and partial breaching have mostly been due to dam face erosion. While spillway erosion is evident to varying degrees among many of the sites, it is not the most common cause of dam failure. Dam face erosion also accounts for most of the impending breaches. Only 4 of the 12 impoundments that are likely to fail soon are expected to be breached from spillway erosion alone.

Cases of dam failure usually involve erosion on both faces of the dam. The erosion processes differ from one face to the other, however (see Table 1). As the erosion proceeds on both faces, the dam narrows, allowing seeps to form on the downstream face. The breach tends to happen from the top down, commonly near the middle of the dam, and may proceed rapidly once it starts, as water is funneled through the breach and accelerates its enlargement. Many breach events probably coincide with major storms causing runoff that exceeds spillway capacity and overtops the dams.

Spillway erosion is more common among the lower elevation settings, between mid slope and the valleys bottoms. This is probably due to the large volumes of water that discharge through the spillways of these relatively large impoundments. The dams tend to be tall and therefore the spillways are steep, which increases the erosive forces of the outflows.

		DECREASING SITE SUSTAINABILITY →				
		Natural Pond	**Stable**	**Threatened**	**Partial Breach**	**Breached**
GEOMORPHIC SETTING	**Ridge Top**	P-006* P-058c* P-118b*	P-032 P-047			*P-318*?
	Colluvial Hollow	P-323 P-326 P-357 P-555	PC-16 P-132 P-331 PC-6b PC-14 P-315 P-030 P-045 P-029 P-574 PC-03 P-040 P-125	P-046 S-1 P-126 *P-031*	P-120	P-119 ***P-311*** *PC-13*?
	Upper Slope			P-130 ***P-325***	***P-059*** ***P-324*** *P-129*	P-131
	Mid Slope	**KEY** P-123 Underlined means breach due to dam face erosion. ***P-123*** Bold italics mean breach due to spillway erosion. *P-123* Underlined italics mean breach due to spillway and dam face erosion. P-123 Plain font means dam not breached.				
	Base of Tributary or Alluvial Fan	PC-01 PC-08 P-118A	P-048 P-053 P-356 P-354	*P-051*	***P-052***	PC-05 ***P-061*** PC-17
	Upper Mainstream Valley	PC-11	P-118a P-050 P-186 P-060	***P-042***	***P-054*** ***P-043***	P-121 PC-07
	Mainstream Valley Bottom	PC-99* PC-100 PC-101	P-181 P-058b P-071	P-168 P-172 ***P-180*** ***P-187***		P-188 *P-185* *P-070* PC-12

Table 2: Distribution of study sites in relation to their geomorphic settings and sustainability scores (see Sections 4.6.1, 4.6.2, and Figure 13). The likely causes of the dam failures at sites P-318 and PC-13 are uncertain.

4.7 Hazardous Impoundments and Impoundments at Risk

A matrix was developed to show the hazard that some upstream sites represent to downstream sites, and the downstream sites' susceptibility to damage if the upstream sites fail (see Table 3 below). Some drainage networks within the study area have two or three impoundments in close proximity to each other (see Figure 6 above). There are two chains of three impoundments each in the Glenbrook drainage. One set consists of sites P-059, P-060, and P-061 on a major tributary, and the other consists of sites PC-13, P-118b, and PC-12 on the lower mainstem. In the steep section of Schooner View Creek drainage, sites P-129, P-130, and P-131 are closely associated with each other. There is another chain of three sites, P-029, P-324, and P-325, near the headwaters of an eastern branch of Home Ranch Creek. A fifth chain of three impoundments, P-186, P-187, and P-188, exists in the small, unnamed drainage at the southern end of the peninsular ridge between Home Bay and Limantour Estero, near the southern terminus of Sunset Trail. There is a pair of closely associated impoundments, P-044 and P-045, on the western flank of this peninsular ridge, and another pair of sites, P-050 and P-181, along the mainstem of Limantour Creek.

Table 3 indicates that P-324, the middle site in the chain of three sites in the eastern headwaters of Home Ranch Creek, is only moderately threatened by the upstream site, P-029, but represents a very high threat to the downstream site, P-325. These are modest impoundments but CRLF have been observed at all three of them. The dam at P-324 is likely to be breached soon by its actively eroding spillway. The downstream site, P-325, is also likely to be breached by spillway incision (see Table 2 above).

The uppermost site along Schooner View Creek, P-129, represents a moderately high threat to the middle site, P-130, which in turn represents a moderately high threat to the downstream site, P-131. Site P-129 has a clogged culvert and a deep gully on the downstream dam face that was previously created by the culvert outfall. The dam is threatened by possible overtopping. Site P-130 has seepage and piping on its downstream dam face, and wave cuts on the upstream face. The middle of the dam is very narrow. Site P-131, the most downstream impoundment, has already been breached due to seepage and piping of the dam face. The small seasonal wetland that remains behind the dam could be destroyed if P-130 fails.

Figure 14: This photo shows the spillway breach in P-061 at the downstream end of the chain of impoundments along a tributary to Glenbrook Creek. A shallow, seasonal pool is retained in the excavation below the base elevation of the dam.

Along the Glenbrook Creek tributary, the most upstream site, P-059, has a moderately high risk of failure. Seeps, piping, and wave erosion have significantly narrowed the dam. If it fails, then the next site downstream, P-060, has a moderately high risk of being damaged. Its spillway is incising deeply into the downstream dam face. The most downstream site in this chain, P-061, has already been breached by spillway incision (Figure 14). The seasonal wetland behind the dam could be destroyed if P-060 fails.

THREAT CLASS	THREAT CLASS	**Threat to Downstream Impoundment from Upstream Impoundment**				
		0 No Downstream Impoundment	**1** Low Threat to Downstream Impoundment	**2** Moderately Low Threat	**3** Moderately High Threat	**4** High Threat to Downstream Impoundment
Threat from Upstream Impoundment to Downstream Impoundment	**4** High Threat from Upstream Impoundment	P-325				P-324
	3 Moderately High Threat from Upstream	P-031 P-131	P-060		P-130	
	2 Moderately Low Threat from Upstream	P-045 P-061				
	1 Low Threat from Upstream	P-181 P-187	P-188			
	0 No Upstream Impoundment		PC-13 P-050 P-186	P-029 P-032 P-044	P-129 P-059	

Table 3: Inter-site hazard matrix for sites within 1000 ft of each other on the same drainage channels. Downstream sites are arrayed along the y-axis, and upstream sites are arrayed along the x-axis. The y-axis indicates the level to which a downstream site is threatened by an upstream site, and the x-axis indicates the level to which an upstream site threatens a downstream site, based on site geomorphic condition (see Sections 4.4 and 4.5). A few sites are between two other sites, and therefore are at once an upstream site and a downstream site. For example, site P-354 is the middle site in chain of three sites, and is highly threatened by an upstream site, while also being highly threatening to a downstream site.

A variety of processes have led to dam failure for the chain of impoundments along the lower mainstem of Glenbrook Creek. The most upstream site, PC-13 is nearly filled with sandy sediments and now functions as a floodplain. The aggraded creek flows past the historical dam and forms a broad, wet fan with dense stands of tall *Cyperus* on the historical inflow delta of site PC-12. Site P-118b consists of shallow pools that have formed within these *Cyperus* stands. The most downstream site in this chain, site PC-12, had a dam that extended across the upper part of Glenbrook Estero. It was apparently breached by wave erosion on both dam faces. Most of the area of the historical impoundment is now intertidal mud flat and fringing salt marsh.

The chain of impoundments east of the southern terminus of Sunset Beach Trail has a unique history. In this case, the most upstream impoundment, site P-186, does not appear to be failing. It has a small catchment in relatively gentle terrain. The middle impoundment, site P-188, has already failed. Its dam apparently extended across the upper reaches of the lowermost impoundment, site P-187, and failed due to a combination of overtopping and wave erosion on both dam faces. Site P-188 is now contiguous with P-187. This lowermost impoundment was originally created behind a dam that spanned the valley bottom, atop a natural wind- and wave-built berm along a high-energy reach of the estero shoreline that is exposed to a long fetch and much wave action during storms. The dam was apparently breached by a combination of wave erosion, overtopping, and spillway incision. But it has since been re-established through wind-wave deposition of sand and wrack along the maximum high water line of the estero.

The mainstem of Big Limantour Creek is impounded by sites P-050 and P-181. These are large reservoirs with substantial dams. They are farther apart than other sites included in this assessment of inter-site hazards, but the large size of the upstream site, P-050, suggests that its failure could affect significant changes far downstream. Site P-050 is well maintained, however, with a substantial drain system and riprap on its downstream face. The downstream site, P-181, was created by building a dam across the historical intertidal flats beyond the valley bottom. Other dams in similar locations have been breached in part by wind-wave action on the downstream dam face. In this case, the dam is protected by a large mud wave that has developed on the estero side of the dam, presumably due to the weight and pressure of the dam and the water behind it on the underlying estuarine silts and clays.

Sites P-044 and P-045 are modest impoundments on a small ephemeral creek draining west to the outer reaches of Home Bay. Cattle have created trails down the dam faces and there is some evidence of spillway incision, but not enough to threaten either dam at this time.

The history of impoundments in a chain suggests some important consequences of their location relative to each other and their geomorphic setting. The most upstream impoundments tend to have a "balanced cut and fill" construction with low dams on small catchments. They tend to fill and spill with most rain storms. Their spillways are usually adequate to convey storm runoff. Infilling tends to be minor and probably does not affect overtopping. If a small, headward impoundment were to be filled with sediment, it would function much like an extension of the seep, spring, or first-order system that serves it. However, channel incision below these sites can increase the bedload supply to downstream impoundments, which then lose some capacity due to sedimentation. This is only significant if the loss of storage capacity in the downstream site increases the flow through the spillway, such that it incises, or if the storm flows exceed the capacity of the spillway, such that the dam is overtopped.

Perhaps the response of downstream sites to storm runoff and upstream dam failures is more important than their gradual in-filling. There is evidence that agriculture has increased the connectivity and density of drainage networks within the study area (Collins and Ketchum 2005). The amount of runoff per storm and its response time have therefore increased. This has little effect on sites that fill and spill with most storm events, unless their spillways are undersized. If the spillways are not sized to accommodate the storm flows then they will tend to incise. If they fill with sediment or vegetation, the dams are more likely to be overtopped. The overtopping can accelerate breaching at places already weakened by wave erosion, seepage, and piping of the dam faces. The problem of undersized spillways can be exacerbated by debris that blocks spillways or vegetation that encroaches into spillways and thus reduces their capacity. The largest reservoirs that fill more gradually might attenuate peak flows early in the rainy season. But after they fill, their ability to attenuate peak flows is negligible.

5.0 Geomorphic Assessment of CRLF Habitat

5.1 Review of CRLF Breeding Habitat Characteristics

In general, CRLF breed from November or December through March or April (USFWS 2007, Storer 1925, Fellers and Guscio 2002, Fellers and Kleeman 2007). Timing may be to assure cool enough temperatures for embryonic survival and enough water to get through metamorphosis (Jennings and Hayes 1989). Although no studies of temperature tolerance have been published for CRLF, the closely related northern red-legged frog, *Rana aurora aurora*, has the lowest lethal embryonic temperature range (4°C to 21ºC) of any North American Ranid (Licht 1971). Adult CRLF show signs of stress at 29ºC (M. Jennings Rana Consulting, personal communication). CRLF tend to be absent where water temperatures exceed 22ºC, particularly when there are no cool, deep areas for refuge. CRLF that breed in streams may need to delay egg-laying until after wintertime high flows (Fellers et al 2001). CRLF eggs are attached to emergent or submergent vegetation at or near the water surface (Hayes and Miyamoto 1984). They hatch in 6 to 14 days, depending on water temperature (Jennings et al 1993). Most larvae metamorphose during July through September, 3.5 to 7 months after egg-laying (Storer 1925). Over-wintering by larvae is not common for this species, but it can occur in areas with especially cool climates, including near the coast at Point Reyes (Fellers et al 2001).

CRLF seem to prefer dense cover of emergent vegetation near the water surface at breeding sites (Jennings and Hayes 1988). Breeding sites might need appropriate cover along at least 25% of their shorelines (Chubb 1999), although this might depend on the size of the site. Larger sites might require less total coverage. Dense cover may help CRLF avoid predation. Larval and adult CRLF are preyed upon by raccoons and other Mustelids (M. Jennings, Rana Consulting, personal communication), wading birds (Fitch 1940, Fox 1952) including great blue herons and night herons (Fellers and Wood 2004), aquatic snakes (Jennings and Hayes 1990, Rathburn and Murphy 1996), native and introduced fishes (Hayes and Jennings 1986), as well as introduced bullfrogs (Lawler et al 1999, Fellers 1995, USFWS 2002, Doubledee et al. 2003). These are mostly sight-predators from which CRLF might be protected by dense vegetation.

CRLF larvae probably feed on algae (Jennings et al. 1992). The adults mostly eat terrestrial and aquatic invertebrates, but will also prey on small vertebrates, such as Pacific treefrogs, stickleback fish, and California mice (Hayes and Tennant 1985, Baldwin and Stanford 1987).

Water depth and hydroperiod are particularly important aspects of CRLF breeding habitat. The water must be shallow enough (and the hydroperiod must be long enough) to support submergent and/or emergent vegetation as oviposition substrate during egg-laying, and as refuge from predation and insulation as the larvae mature. If CRLF has a preference for cool water it probably doesn't translate into a preference for deep water, since emergent and submergent vegetation can keep very shallow water cool through shading (Collins et al. 1985). Perennial sites that are deep enough to support predatory fishes, crayfish, and bullfrogs will not usually be good CRLF breeding sites (Allen and Tennant 2000), unless they have densely vegetated shallows that provide adequate refuge (M. Jennings, Rana Consulting, personal communication).

With regard to depth and hydroperiod, the optimal CRLF breeding site might be deep enough from November to July for egg-laying and metamorphosis, and thereafter too shallow for bullfrogs and other aquatic predators. This suggests that knowing the minimum depth for metamorphosis in summertime is critical to assess a site as potential breeding habitat. Different studies of CRLF habitat have reported different minimum depths for breeding sites, ranging from 70 cm in the Sacramento Valley (Hayes and Jennnings 1988), to between 26 and 50 cm in Santa Clara Valley (Reis 1999). The variation in breeding site depths may reflect what is available, rather than what is needed. The records that have accumulated since these two studies were completed suggest that most breeding sites are deeper than 25 cm (Fellers 2005), but there are a few records of CRLF in isolated sites less than 10 cm deep (Fellers and Guscio 2004).

For coastal populations of CRLF, water salinity can be an important aspect of a breeding site. CRLF eggs cannot tolerate water salinities greater than 4.5 ppt (Jennings and Hayes 1990). Adult and sub-adult CRLF can tolerate 7.0 ppt (Jennings and Hayes 1990). In the current study, sub-adults were observed in a layer of water less than 5 cm deep at 7.0 ppt, overlaying water at 12 ppt, in a quiet pool less than 50 cm deep near the high tide contour. Adult CRLF have been found at salinities ranging from 0.2 ppt to 1.1 ppt at Horseshow Pond, across Drakes Bay from the study area (Fellers and Guscio 2002).

Adult CRLF may stay within perennial breeding sites year-round, or they may move from breeding sites to non-breeding habitat (Fellers and Kleeman 2007). Seasonal breeding sites must be abandoned before they desiccate (USFWS 2005). Adult and sub-adult CRLF may move up to 3,000 m without obvious regard for topography or vegetation type (Bulger 1998, Bulger et al 2003). This probably approaches a maximum dispersal distance (USFWS 2005). Most dispersal from breeding sites is less than 1,200 m long, however (USFWS 2005). Many adult CRLF may move much less (Fellers and Guscio 2004, Fellers and Kleeman 2007, Tatarian 2007). Dispersal movements are typically along riparian corridors with dense vegetation (Rathburn et al 1993, Tatarian 2007, Jennings and Hayes 1994), but some individuals (especially on rainy nights) move across grazed pastures, oak-grassland savannas, or other relatively open areas (Fellers 2005, Fellers and Kleeman 2007). Near Redwood Creek in Marin County south of the study area, the dispersal distances of CRLF ranged from 30 m to 1400 m, with a median distance of 150 m. They tended to disperse into riparian corridors near the breeding sites, but open pastures were not always avoided (Fellers and Guscio 2004).

Non-breeding habitat can include nearly any area within 2–3 km of a breeding site that stays moist and cool through the summer months (USFWS 2002), but areas with 60 m of breeding sites are more intensively used (USFWS 2005). In the Coast Ranges, suitable non-breeding habitat is characterized by dense coastal scrub (coyote bush, *Baccharis pilularis*, and California blackberry, *Rubus ursinus*), willow (*Salix* spp), and California bay trees (*Umbellularia californica*). The non-breeding habitat used by CRLF can be very limited in size; a 2-m wide *Baccharis* thicket growing along an intermittent creek surrounded by heavily grazed pasture might suffice (Fellers 2005).

Breeding sites are best when they are associated with sheltering and dispersal habitat, and other breeding sites, within a range of about 1,200 m (USFWS 2002). The particular spatial arrangement habitat patches and the condition of their landscape matrix across distance greater than 1,200 m can also affect the local CRLF populations (USFWS 2005). A general survey of known breeding sites within the Bay Area reveals, however, that many sites are relatively isolated from each other and from sheltering habitat, lack abundant emergent or submergent vegetation, and are located amidst agricultural fields and even more intensive land uses. CRLF will use a broad range of breeding sites depending on what is available. The amount of disturbance to which their natural habitat has been subjected throughout much of their range increases the difficulty of defining reference conditions against which existing habitat can be compared.

Previous CRLF surveys (Fellers and Guscio 2002, Fellers ad Osbourn 2004) included 58 of the 72 sites visited in the current study. These surveys detected CRLF in 27 of these 58 sites. CRLF were detected in another 4 of these 58 sites during the current study. CRLF were not detected in the 12 additional sites included in the current study but not in the previous CRLF surveys.

5.2 Geomorphic Characteristics of Known CRLF Breeding Sites

The sites with CRLF represent the full range of geomorphic settings and site sustainability (see Table 4 on next page). Ten of these sites are likely to become at least partially breached in the foreseeable future, and another five sites are already partially breached. Half of the sites with CRLF are at risk of partial or complete breaching (Figure 15).

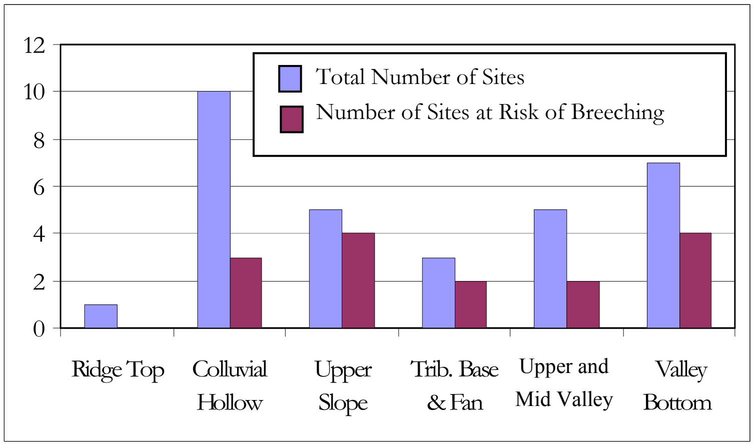


Figure 15: Sites of CRLF detection in relation to geomorphic setting and site sustainability. Sites that are partially breached or that are likely to become breached are pooled together as sites at risk (see Table 4). Sites not at risk include stable sites and sites already fully breached.

Whether or not such breaching eliminates CRLF breeding habitat depends in part on the residual impoundment left behind the dams after they are breached. Sites that are excavated below the base elevations of their dams might retain enough water to support CRLF breeding. For example, site P-061 has been breached (see Figure 14) but at least one adult CRLF has been observed in the residual impoundment during the breeding season (see Table 4). The current study was not a survey for CRLF. Although the field team has experience conducting amphibian habitat surveys (Appendix 4), any detections of CRLF during this study were incidental to the assessments of the geomorphic and ecological conditions of impoundments in the study area.

Pond ID	Fellers& Guscio (2002)	Fellers & Osbourn (2004)	Collins & Collins (2007)	Geomorphic Setting	Site Condition (based on Site Sustainability Index)
P-006	T, A		SA	Valley Bottom	natural
P-029		A		Colluvial Hollow	stable
P-030		A		Colluvial Hollow	stable
P-031		A		Colluvial Hollow	threatened
P-032		A		Ridge Top	stable
P-042		A, SA		Upper and Mid Valley	threatened
P-050			A	Upper and Mid Valley	stable
P-051		A		Trib. Base and Fan	stable
P-052		A		Trib. Base and Fan	partially breached
P-054		A		Upper and Mid Valley	partially breached
P-058b		A		Valley Bottom	stable
P-059		A		Upper Slope	partially breached
P-060		A, SA		Upper and Mid Valley	stable
P-061		A		Trib. Base and Fan	breached
P-119		A		Colluvial Hollow	breached
P-120		A, SA		Colluvial Hollow	partially breached
P-121		A		Upper and Mid Valley	breached
P-126		A, SA		Colluvial Hollow	threatened
P-130		A		Upper Slope	threatened
P-132		A		Colluvial Hollow	stable
P-168			A	Valley Bottom	threatened
P-172			SA	Valley Bottom	threatened
P-180		A		Valley Bottom	threatened
P-187			SA	Valley Bottom	threatened
P-311		A		Colluvial Hollow	breached
P-315		A		Colluvial Hollow	stable
P-324		A		Upper Slope	partially breached
P-325		A		Upper Slope	threatened
P-354		A		Upper Slope	stable
P-555	T, A			Valley Bottom	stable
P-574	A			Colluvial Hollow	stable

Table 4: Geomorphic setting and site sustainability status for sites where CRLF have been observed as either tadpoles (T), adults (A), or sub-adults (SA) during the studies referenced in this table. Sites highlighted in yellow are threatened by erosion, and sites highlighted in red are already partially breached.

6.0 Possible CRLF Habitat in the Native Landscape

6.1 Key Assumptions

The term, native landscape, refers to the distribution, form, and ecological functions of the lands and waters of the study area as they existed for the century or so before European contact. The following discussion of historical habitats for CRLF is based on a few key assumptions.

- CRLF inhabited the native landscape. While the study area is near the northern coastal limit of the geographic range of CRLF, there is no indication that the study area is part of a range extension that occurred since European contact. There is no record of the specific locations of breeding habitat in the native landscape, however. There were no lakes or other natural features analogous to the perennial impoundments (i.e., stock ponds and reservoirs) that are prominent features in the study area.
- The habitat for CRLF was mostly undisturbed prior to European contact. There is no evidence that the indigenous people, the Coast Miwok, had any major impact on the distribution or abundance of CRLF. The Coast Miwok harvested a variety of wetland plants as food, medicine, and building materials (Anderson 2005), but there is no evidence that they altered the hydrology or configuration of streams or wetlands in any major way that would affect CRLF populations (Chuck Striplen, SFEI, personal communication). Although CRLF were over-harvested elsewhere in California by European settlers in the late nineteenth century (Collins 2004), there is no evidence that either the settlers of the Coast Miwok exploited CRLF populations at Point Reyes.
- In the absence of any land use impacts, the distribution, abundance, and temporal aspects of CRLF habitat are controlled by geomorphology, hydrology and climate. A general description of the native landscape, including the distribution of habitat for CRLF, can be inferred from an understanding of these natural habitat controls.

6.2 Sources of Evidence of Native Conditions

The description of the native landscape of the study area is based on historical maps, historical aerial photography, and geomorphological analyses of the study area and comparable areas elsewhere in the greater San Francisco Bay Area.

The earliest verifiable maps of the study area are the Topographic Sheets (aka "T-sheets") of the First Survey of the U.S. Coast Survey (circa 1859-60). They post-date European contact by more than a century, but they pre-date the peak in agriculture, and are the best single source of information about the native landscape (Collins et al. 2003, Grossinger et al. 2005). The local T-sheets do not extend to the top of Inverness Ridge, but they include the larger valleys and adjacent peninsulas that comprise most of the study area. There is close agreement between the remnant features of the native landscape as shown in recent aerial photography and the historical depiction of these same features on the T-sheets (see Figure 18).

The earliest historical aerial photography reviewed for this study was produced by the U.S. Department of Agriculture in 1942. This and subsequent aerial imagery from the second half of the third quarter of the 20th century documents much of the historical landscape change due to agriculture. The historical photography is well complimented by local treatments of 19th and 20th century human history for the study area (e.g., Toogood 1980, Livingston 1994).

Figure 18: Overlay of USCS T-sheet 805 ca 1859-60 (contour lines, shorelines, and wetland outlines) on aerial imagery ca 2005 showing close agreement between historical and current shape, size, and location of site PC-11, a natural seasonal wetland on the peninsula between Home Ranch Valley and Schooner Bay.

There are a variety of recent geomorphic analyses of native landscapes within the region that are relevant to the current study. For example, there are analyses of the nearby coastal watersheds of Rodeo Lagoon (Striplen et al. 2006) and San Pedro Creek (Collins et al. 2001). These watersheds have very similar geology and climate as the study area. There are historical geomorphic analyses of Novato Creek (Collins 1998) and San Antonio Creek (Collins et al 2000) in eastern Marin County, and of Sonoma Creek (Sonoma Ecology Center et al. 2006) and the Napa River (Grossinger et al 2007) in southern Sonoma and Napa Counties, plus analyses of Coyote Creek (Grossinger et al. 2006), and Alameda Creek (Collins 2007) in Alameda and Santa Clara Counties that provide evidence of common characteristics of native Bay Area watersheds. These studies also provide evidence of predictable landscape responses to dairying and ranching practices that were historically common throughout the region, including the study area.

6.3 Description of the Native Landscape

The preponderance of evidence suggests that the native landscape was very different from modern landscape. While there are a few natural wetlands in bedrock-controlled, topographic lows that have persisted since European contact (see Figure 18), the distribution of streams, wetlands, and riparian habitats within the study area was greatly impacted by the agricultural practices and land developments that preceded establishment of the National Seashore (PRNS).. The kinds of features that natural geomorphic processes created in the native landscape are illustrated in Figures 19-22, and listed in Table 5 below, with reference to existing examples.

The Vision Fire of 1995 revealed that drainage networks in the middle and upper reaches of Muddy Hollow Creek watershed had numerous low-order channels that were discontinuous, not connecting to the mainstream channel (Collins and Ketcham 2005). The channels were disconnected by small alluvial fans. Observations made by L. Collins and Dr. William Dietrich (U.C Berkeley Department of Earth and Planetary Sciences) in an upper, un-grazed watershed along Tomales Bay State Park revealed a similar pattern of discontinuous channels. Early maps from the 1800s of Novato Creek (Collins 1998), San Antonio Creek (Collins et al 2006), Napa River (Grossinger et al. 2007), Sonoma Creek (Sonoma Ecology Center et al. 2006), and San Pedro Creek (Collins et al 2001), show numerous examples of tributaries terminating in alluvial fans or in wet meadows apart from mainstream channels.

Because of their discontinuous drainage networks, the native watersheds had slower response times to rainfall than the existing watersheds. Overall, the native watersheds would have retained water longer. The runoff had to pass through dense plant cover, spongy soils, alluvial fans, and shallow aquifers to reach the gaining reaches of the channel network. The storm hydrograph would have been drawn-out with lower peaks, compared to present-day hydrographs. Higher water tables and greater water retention would have maintained greater base flow in mainstem channels. This would have supported riparian forests with closed canopies that shaded the streams. Base flows would have been cool and continuous throughout most of the year.

Groundwater would have emerged at various locations along the toes of alluvial fans and in topographic lows along the backside of natural stream levees along the valley bottoms. Examples of such levees and associated wetlands can be seen today adjacent to Muddy Hollow Creek downstream of the lower Muddy Hollow parking lot (see Photo of site P-058c, Page 41), at the Coast Trail crossing of Laguna Creek, and between sites P-050 and P-051. Emerging groundwater at the base of some hillsides probably created elongated seasonal pools. Such pools are evident along the tidal marsh backshore on the upper south side of Tomales Bay.

Emerging groundwater would have been most abundant in the transitional areas between the valley bottoms and adjoining intertidal zones. In these areas, the less dense, non-saline shallow groundwater moving down-valley would have risen over the denser, saltier, shallow groundwater near the intertidal zone. In especially wet years, the shallow freshwater flow might have risen to the ground surface further up the valleys, far above the intertidal zones. The groundwater "saturation zones" across the valley bottoms would have supported isolated willows groves, termed sausals in the historical vernacular, amidst wet meadows with seasonal pools in channel scars and other isolated topographic lows. Examples of these kinds of wetlands can be seen along the Eastern flank of Home Ranch Valley, adjacent to the recent breach of the historical diversion ditch for Home Ranch Creek.

Riparian forests would have been restricted from areas of the valley bottoms having persistent saturation and little groundwater flow in the root zone. The riparian corridor would have been largely confined to the more aerated soils associated with draw-down of the water table along the immediate margins of the active channels.

Some of the valleys terminated in natural lagoons that impounded runoff and emergent groundwater behind wave-built berms along the high tide contour. These lagoons would have been brackish in part due to occasional breaching during major storms, overtopping by extreme tides, and retention of salt deposited by the wind. For most of the time, they would be brackish nearest the tidal zone, and fresher upstream, due to a nearly continuous supply of freshwater from their adjoining wet valleys. Site P-187 might be an example of what lagoons were like in the native landscape (see Photo 7, page 41). The dam at P-187 was naturally breached, and has since been evolving into a naturalistic lagoon.

It's interesting to note that CRLF has a variety of adaptations for inhabiting the fluvial-palustrine-tidal interface, including coastal lagoons. The most notable adaptation is the tolerance of CRLF to brackish conditions. CRLF larvae can tolerate at least 4 ppt salinity, and adults can tolerate 7 ppt (Jennings and Hayes 1990). In the current study, sub-adult CRLF were found in shallow pools of 7 ppt salinity surrounded by salt grass (*Distichlis spicata*) in the brackish saturation zone near P-187 and P-006. However, lagoons might not always be breeding habitat for CRLF. Monitoring has shown that although some lagoons attract adult CRLF, its breeding success in these locations can be highly variable. When Horseshoe Pond north of the study area was breached to restore it as a coastal lagoon, the total number of CRLF decreased substantially (Brannon Ketcham, PRNS, personal communication).

There is speculation that CRLF has generally high fidelity to breeding sites. The relatively unchanging, artificial impoundments that comprise much of breeding habitat in the modern landscape provide opportunities for site fidelity that are essentially unmatched in the native landscape of the study area. In the native landscape, most CRLF breeding would have been supported by a broad array of geomorphic features, including wet meadows, sausals, riparian forests, natural levees, in-stream scour pools, meander cutoffs, channel scars, tree throw pools, and seasonal wetlands in topographic lows associated with dynamic fluvial processes. The distribution and abundance of breeding habitat changed from year to year. Reproductive success varied with the timing and nature of seasonal rainfall. In many watersheds, access to breeding habitat might only be assured at the valley scale. In the context of the dynamic nature of breeding habitat in the native landscape, site fidelity might refer to whole valleys or areas of valleys where breeding habitat tended to occur during most years. Valleys with lagoons might have provided more assurances of breeding habitat than valleys without lagoons.

Geomorphic Setting	Feature	Existing Example
Ridge Tops	bedrock-controlled topographic depressions	• P-323 and PC-11
Colluvial Hollows, Upper Slopes, Tributary bases and Alluvial Fans	seeps and springs behind hillside rotational slumps	• Orinda Formation in Wildcat Canyon, Contra Costa County
	in-stream pools in fluvial channels, including brackish reaches of estuarine channels	• Round Valley Creek, Contra Costa County • estuarine channel below P-187
Upper Valleys, Mid Valleys, and Valley Bottoms	depressional wetland behind fluvial levees	• Muddy Hollow valley • Home Ranch valley (at levee breach) • wet meadow below P-058c
	remnant channel pools and depressional wetlands on floodplains and low terraces	• Sonoma Creek, Sonoma County • Calera Creek, San Mateo County • Olema Creek near Olema, Marin County • floodplain at P-006 • delta above P-356
	channel scars and tree-throw pools on floodplains, low terraces, and on deltas of lakes, reservoirs and lagoons	• delta above Muddy Hollow reservoir • delta above P-050 • delta above P-181
	sag ponds	• sag ponds at Dogtown, Marin County
	Brackish wetlands at intersection of tidal marsh and seeps and springs	• west side of Giacomini wetlands, upper Tomales Bay, Marin County

Table 5: Existing examples of wetlands and aquatic features that were common in native landscapes of the Bay Area, including the study area.

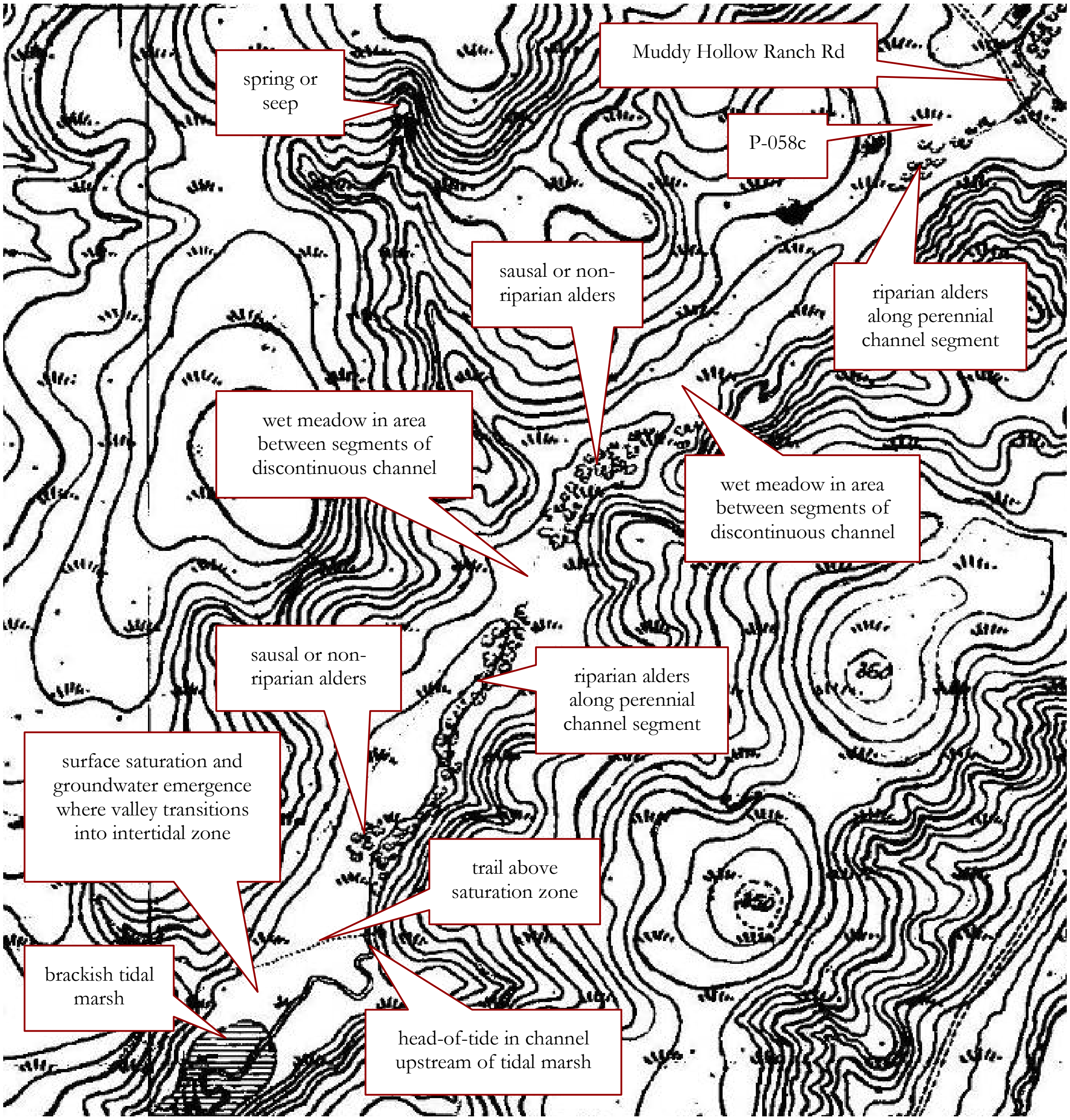


Figure 19: Natural riparian and wetland features of the native landscape in lower Muddy Hollow watershed as shown on USCS T-sheet 805 ca 1859-60. A variety of features were historically distributed along the typically discontinuous mainstem channel. The channel segments were probably gaining reaches with perennial in-stream pools. A narrow forest of alders bordered the channel segments. On the floodplains beside the riparian forests and between the channel segments were wet meadows with channel scars and pool remnants. Sausals (stand-alone groves of willows) existed at the upstream margins of the wet meadows. The channel scars and tree-throw pools within the alder forests and sausals probably only held water during the rainy season. Further downstream, where the valley transitioned into the intertidal zone, the valley stayed wet due to groundwater emergence. Channel scars in this area could have held water year-round. The tidal marsh would have varied in salinity from brackish to saline with distance into the estero. The tidal excursion in the channel would have extended upstream into the saturation zone. The valley below Muddy Hollow Ranch Road was not cleared, drained, channelized, or otherwise developed for agriculture or other land uses until after WWII. These later developments, especially discing, ditching between channel segments, and subsequent re-alignment and incision of the channel helped to de-water the valley and remove many of the natural riparian and floodplain features. Site P-058c may be a remnant of an historical wet meadow system that existed between the hillside and the natural levee of Muddy Hollow Creek.

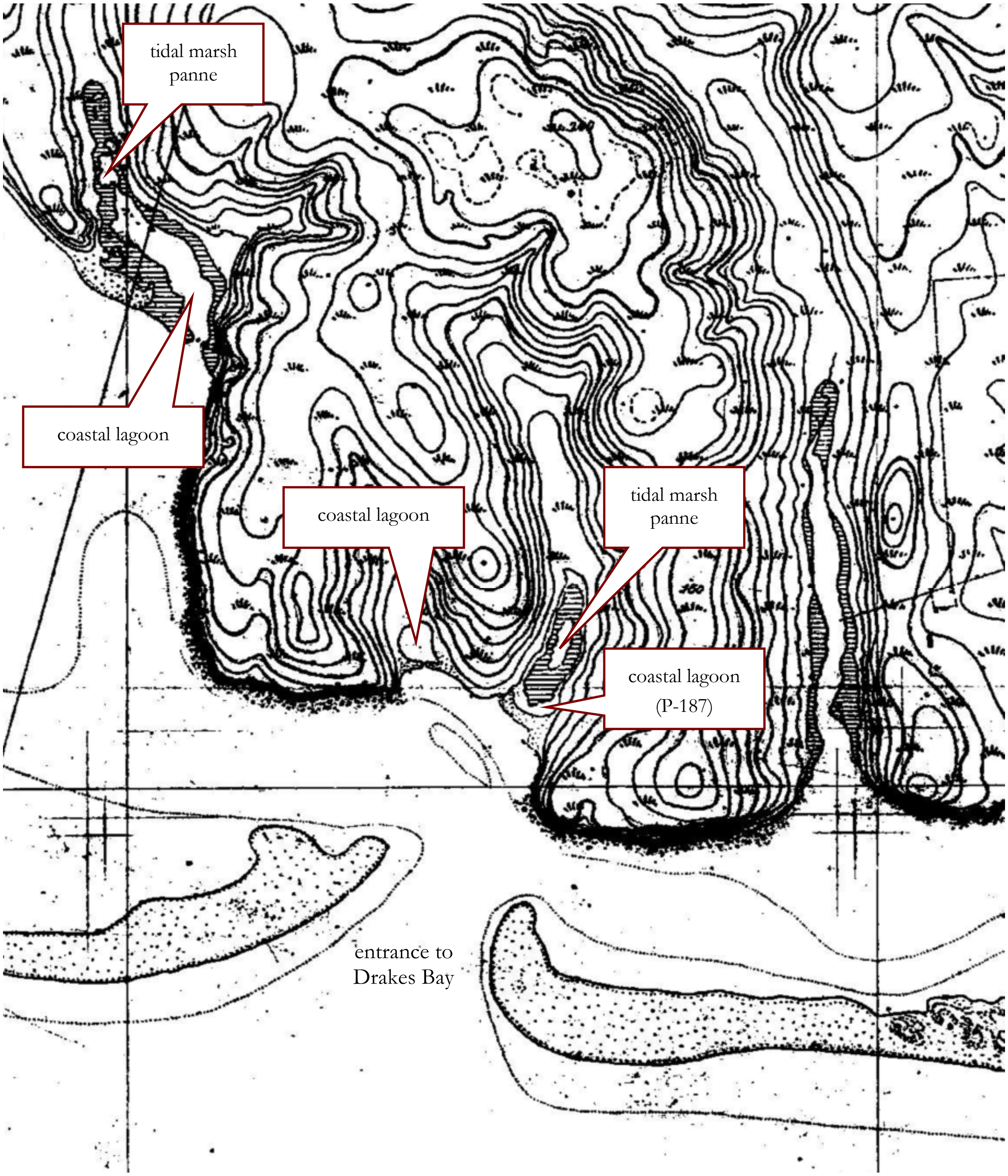


Figure 20: Coastal lagoons and tidal marsh pannes of the native intertidal landscape opposite the entrance to Drakes Bay, as shown on the USCS T-sheet 805 ca 1859-60. The lagoons formed behind barrier berms of sand built by wind-generated waves. The berms would have been naturally breached by storm waves and storm runoff, and subsequently re-established. Some of the lagoons had fringing tidal marsh with pannes. The upper ends of the lagoons would have been fresh to brackish, and the pannes would have been brackish to saline, depending on the amount of freshwater runoff and groundwater they received. The valley bottoms just above the lagoons and tidal marsh were flood plains saturated with groundwater and subject to inundation by storm runoff. Any topographic depressions such as channel scars or in-stream pools would have held water at least during the wet season. Site P-187 is a lagoon that has evolved from a breached stock pond, which was apparently constructed by damming a natural lagoon.

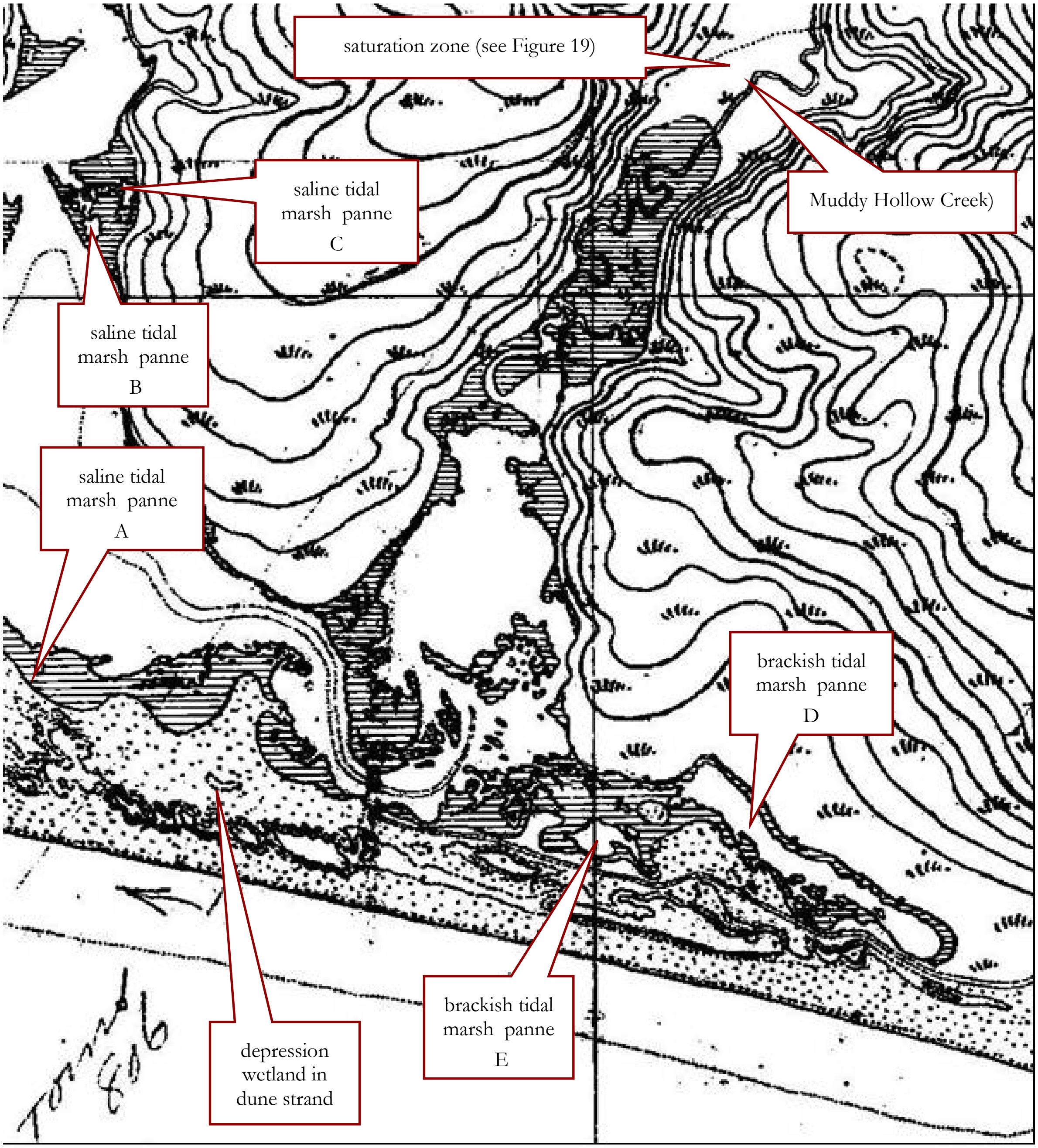


Figure 21: Intertidal pannes of the upper Limantour Estero away from any direct fluvial inputs of freshwater, as indicated by USCS T-sheet 805 ca 1859-60. Pannes A-C were probably saline due to their isolation from hillside runoff or emergent groundwater, as well as their isolation from local streams. Panne D would have received hillside runoff and was probably brackish, at least during the rainy season. The large size of this pond also indicates that it was probably brackish (Grossinger 1995, Collins and Grossinger 2004). Although panne E was isolated from any direct freshwater sources, it might have been brackish due to its upstream position within the brackish zone of the estero. The dune strand contained a few depressional wetlands that would have been fresh, given that their main source of water was direct precipitation or rainfall filtered through their sandy catchments.

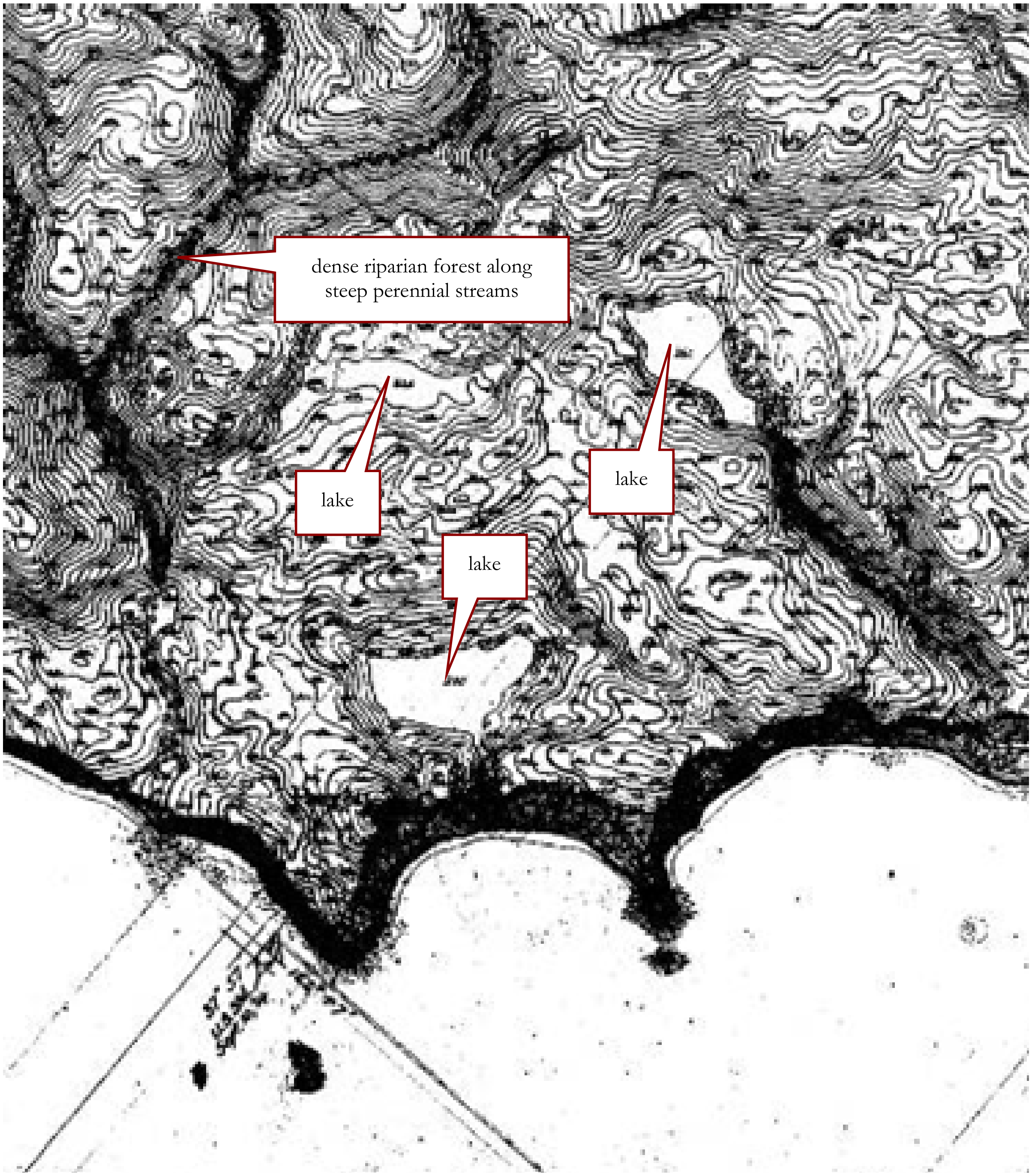


Figure 22: Natural lakes associated with the large landslides near Double Point, just south of the study area, as shown on USCS T-sheet 807 ca 1859-60. Natural lakes never existed within the study area and rare in the PRNS except at this locale. Reservoirs similar in size to these lakes were constructed in the study area shortly before the PRNS was established. Assuming that these lakes lacked fishes, then their fringing wetlands may have been breeding habitat for CRLF. The dense, narrow, riparian forests shown in this map are typical of the steep, headwater streams of the study area.

7.0 Analysis of Historical Landscape Alterations

Land use since Euroamerican settlement has directly effected every place in the study area. Ranching and dairy operations flourished in the area for more than a century and a half (Livingston 1994). Although the remaining dairies and ranches are celebrated examples of rural life and commerce, others have come and gone, leaving a legacy of past landscape change.

There is abundant evidence in the field and in historical maps and photos that early European settlers ditched the land and diverted water for both irrigation and drainage purposes. In some areas tributaries were ditched across their alluvial fans and perennial streams were moved from the middle of their valleys to their margins to gain pasturelands and to improve access across the valley bottoms. "Drain and reclaim" was a prominent mind set of the time.

The analysis of historical maps and photos revealed that small stock ponds began to be created for dairies in the early 20th century at the higher elevations that lacked surface water storage. Windmills were used to lift shallow groundwater into watering tanks along the ridge lines. Damming proceeded down the tributary drainages before World War II.

Road grades along and across the lower valley bottoms were elevated to protect them from the high water table and from flooding. These road grades along the valleys reduced the flood-prone width of the mainstem creeks. The crossroads intercepted natural drainage patterns and required culverts or other structures that were usually undersized for floods.

The larger valleys were eventually separated from their adjoining intertidal zones by levees and impoundments. Some early, low dams that cut across the intertidal zone might have been constructed to restrict tidal excursion and trap sediment to build additional pasturage. Such reclamation is known to have been conducted elsewhere in the region. The saturation zones near the valley mouths, where the freshwater influences of watershed drainage and groundwater discharge interfaced with the tidal influences of the esteros, were substantially diminished by dewatering the lower valleys through ditching and channelization of runoff, and by reclaiming the valleys from the tides. The historically broad zones of saturation and transition from terrestrial-fluvial to estuarine-tidal influences were compressed into narrow bands of brackish conditions along the estero-sides of dams and dikes. In the last decades before the PRNS was established, relatively large reservoirs and roads with inboard ditches were constructed as part of large-scale land development schemes.

These activities had major cumulative environmental effects. In essence, initial ditching to enhance drainage across tributary fans and through valleys increased the overall length of channel per unit area of land (i.e. drainage density was increased). This created more hydrological connectivity between streams and their hillsides. Therefore, runoff per unit area also increased. The straightening of mainstream channels along the major valleys and their increase in discharge caused the channels to incise. Conversion of coastal shrub and perennial coastal prairie to heavily grazed annual grasslands, and the concomitant reductions in thatch cover and soil permeability also increased the amount of runoff, which in turn accelerated the rates of channel incision and bank erosion. Increased runoff from roads and overgrazed hillsides caused severe gullying and chronic degradation of the upper and middle reaches of the mainstream channels. The down-cutting in some mainstream channels created nick points or gully heads that tended to move headward into the ditches and natural tributaries, extending the incision upslope in some cases. This further increased the drainage density, runoff, and downstream channel incision.

Channels became deeply entrenched in their middle and upper valleys, effectively disconnecting themselves from their historically broad floodplains and flood-prone terraces. The process of channel entrenchment was self-perpetuating as the channel cut down it conveyed deeper flows with greater sheer force than the shallower flows of equivalent volume that would have spread across the floodplain. The chronic channel incision helped dewater the valley floors.

The construction of dams throughout the headward portions of channel networks further accelerated the rates of incision downstream by creating the "hungry water effect." That is, as bedload became entrapped by upstream impoundments, the downstream energy that had been used to convey the bedload began "eating" the channel beds and banks.

The abundance of ditches and incised channels effectively drained the land surface, and the channel incision tended to also lower the groundwater. Many areas experienced a net loss in surface water storage. This increased the need to impound runoff for agricultural uses.

While the upper and middle portions of the mainstem channels became severely entrenched, the lower reaches near the valley bottoms aggraded. Deltas extended into the downstream impoundments or onto fringing tidal marshlands. In essence, the sediment that eroded from upstream was piled downstream where the channel gradients flattened. Large pulses of sediment are evident as sediment lobes on deltas that can be dated by the ages of the riparian trees they support. Some pulses were created by upstream dam failures and hillside mass-wasting episodes during major storms. For example, a number of delta-forming episodes are evident at site P-054 in "West Home Creek" drainage that clearly pertains to rather sudden changes in upstream drainage conditions (see photo of site P-054 on page 41).

There have been three significant geomorphic events in the study area since cattle grazing was discontinued. The very wet winter of 1982 brought torrents of rain that caused abundant landslides, sediment pulses in the creeks, and significant local flooding. A number of impoundments were overtopped and breached. The Vision Fire in 1995 generated large sediment loads that contributed to the formation of deltas in many impoundments. The 1998 El Nino brought the second highest annual rainfall total on record.

Within the Wilderness, where the watersheds are recovering from the Vision Fire of 1995 but have not been grazed in decades, the rate of channel incision in the mid and lower mainstream valleys seems to be slowing, and nascent floodplain benches are evident within some channels. Bed incision is being replaced by bank erosion as the channels create new, narrow, inner floodplains. The rapid growth of alders and willows, with their dense networks of roots, buttress the channel banks, slowing their erosion and prolonging the process of inner floodplain formation. Since willows and alders are short-lived, and since they regenerate rapidly, they can provide abundant woody debris. This creates debris jams that trap bedload and slow incision.

Where intensive agriculture was halted, the hillsides and valleys are starting to recover. Some unused roads have been put-to-bed, and some hillside gullies are becoming stable. Some existing roads are still important sources of runoff and sediment, however. Groundwater levels are apparently rising at valley bottoms, the toes of alluvial fans, and the bases of hillsides.

Now, with efforts by the National Park Service to manage the lands as wilderness, natural geomorphic processes are less constrained than at any time in the last 150 years. Some creeks that were diverted into ditches have avulsed and are re-establishing natural channels and accessing valley flats as floodplains. This is especially evident in Muddy Hollow watershed and Home Ranch watershed. Muddy Holly Creek began avulsing after the severe storm of January 1982, when large sediment loads caused the channel bed to aggrade rapidly, and then avulsed further after the Vision Fire (Collins and Ketcham 2005). An increase in sediment supply also contributed to the avulsion of the lowermost reach of the historical diversion ditch for Home Ranch Creek. These avulsions have created new distributary channels, sediment splays, wet meadows, and other freshwater wetlands.

As reported in Section 4 above, many of the historical impoundments that are not maintained are in various stages of disrepair (See Figure 13 and Table 2). Assuming that people, property, and infrastructure can be protected, then the failure of some dams could have ecological benefits. Dam failure would release large amounts of stored sediment that could force some downstream channels to aggrade and avulse, potentially ameliorating some of the entrenchment problems. On the other hand, dam failure would mean the loss of relatively permanent aquatic, wetland, and riparian habitats associated with the impoundments. There could be a net loss in aquatic habitat overall, and a temporary loss of wetland and riparian habitat until the downstream fluvial systems achieves its new dynamic equilibrium. Where dams in the Upper and Mid Valley settings have failed, dense riparian alder forests now exist (e.g., P-054, PC-07, PC-17), with off-channel floodplain pools and stable stream courses. Whether or not these riparian corridors provide CRLF breeding habitat has not been determined for this project. Streams and riparian areas are not well represented in the existing surveys for CRLF in the study area.

8.0 Conclusions and Recommendations

8.1 How are the dams doing?

Numerous earthen dams were constructed in the study area during the 150 years between Euroamerican settlement of the study area and its dedication as wilderness. These dams impounded local runoff for agriculture, domestic uses, and recreation. Each impoundment within the study has been assessed in terms of its own geomorphic condition and in terms of its risk to or from other impoundments.

The dams are deteriorating due to seepage, piping, wave erosion, and overtopping. Spillway incision is a lesser problem than dam face erosion, although spillway blockage can increase the risk of overtopping, which seems to be one of the major cause of dam failure. The dams may have been especially susceptible to surface and wave erosion before they were colonized by vegetation. Most dams that haven't been breached support abundant wetland vegetation along their waterlines, and coastal scrub vegetation on their downstream faces. This vegetation helps protect the dams from surface erosion.

Some dams are filling in with sediment through fluvial and/or hillslope processes. For some dams with large catchments, in-filling has significantly decreased their size and water-holding capacity. Lack of adequate drainage due to undersized spillways or blockage of spillways and has increased the likelihood of dams being overtopped. Because the impoundments at the higher elevations are small, with small catchments, they are not as likely to be overtopped. The smaller impoundments near the ridge tops are generally in better shape than the larger impoundments further downstream.

Few, if any, of the dams were rigorously engineered. They appear to lack a solid core, although some support roads and have been compacted by road use, which has somewhat increased their resistance to erosion. But none of the dams are secure, even if they are stable at this time. Ten of the 72 dams mapped for this study have already failed, most within the last 20 years. Another 22 have been partially breached or are expected to be breached within the foreseeable future.

There are few records about the construction of the dams. Their dates of construction are not easily determined. Aerial photography can be used to assign the dams to minimum age classes, based on the dates of the photography, but the classes are necessarily broad and therefore not particularly helpful (see Appendix 1). There has been little or no monitoring of dam condition, or accounting of maintenance efforts prior to establishment of the PRNS. The rates of dam deterioration can only be inferred from indirect measurements. Based on the size and age of trees and shrubs growing on sediments deposited by eroding spillways and dam faces, it seems that most of the threatened dams will not last another 20 years. Major storms that generate floods during especially wet winters may accelerate breaching in some cases. A number of major breaches seem to date back to either the major storm of January 1982, or the El Nino event of 1998. A few consecutive wet years punctuated by deluge will very likely mark the demise of many of the most weakened and threatened dams.

8.2 What about the impoundments that are used by CRLF?

Previous surveys have revealed that the California red-legged frog (CRLF) occupies impoundments and associated riparian areas throughout the Wilderness. CRLF use of relatively natural habitats, such as streams, floodplains, and flood-prone terraces has not been as thoroughly investigated as CRLF use of impoundments. However, based on the studies to-date, it seems that impoundments provide most of the breeding habitat for CRLF in the study area.

Many of the impoundments where CRLF were detected, and many of the most promising candidate sites, are at risk of being breached. If there is a need or desire to conserve any impoundments as CRLF breeding habitat, then the results of this study can be combined with the results of the CRLF surveys to prioritize the conservation efforts. Based on the data at hand, P-052, P-054, P-059, P-120, and P-324 are the sites at greatest risk of complete failure where CRLF have been detected. Sites P-031, P-042, P-051, P-126, P-130, P-168, P-172, P-180, P-187, and P-325 are threatened by ongoing erosion of the dam faces and/or spillways. Sites P-324, P-130, and P-059 are also threats to other impoundments.

8.3 Where were the CRLF before there were dams?

The landscape within the study area is much different now than it was before the advent of European agriculture. The existing impoundments had no natural analogues in the native landscape. There are wetlands in colluvial hollows and in topographic depressions on flat ridge tops that also existed in the native landscape, but they apparently do not function as breeding habitat for CRLF. No CRLF have been detected in these kinds of natural habitats. They are small, isolated, uncommon, and seasonal. They might function as refuge and sheltering habitat by dispersing CRLF, but this possible function has not been investigated.

It is unlikely that CRLF were absent from the native landscape of the study area. The entire National Seashore is within the expected historical range of CRLF. Adult CRLF are found in nearby natural lagoons, such as Abbotts Lagoon to the northwest, and natural lakes, such as Crystal Lake to the southeast, that were part of the native landscape. But whether CRLF was historically more abundant or less abundant in the study area than it is now is undetermined.

A discussion about the distribution and abundance of CRLF in the native landscape can be framed by the following conceptual model of natural fluvial processes and tidal processes and features that characterized the native landscape. This model will need to be translated by CRLF ecologists into assessments of breeding and non-breeding habitat.

The native landscape supported the California red-legged frog (CRLF). Each watersheds draining from Mount Vision or Point Reyes Hill to Drakes Bay and its esteros contained a complex mosaic of fluvial channels, in-stream pools, riparian forests, tree-throw pools, natural levees, meander cut-offs, wet meadows, groundwater-fed seasonal wetlands, and brackish tidal marsh pannes that served as breeding and non-breeding habitats for CRLF. Some watersheds also supported coastal lagoons. The distribution and abundance of the CRLF habitats were mainly controlled by dynamic fluvial processes operating on the floodplains and flood-prone terraces of the mainstem valleys and major tributaries. All requirements of the CRLF for over-wintering, breeding, and dispersal were met within the mosaic, but the quantity and quality of habitat depended on the amount and timing of seasonal rains. During wet years, CRLF had a variety of freshwater habitats throughout the valleys. During prolonged droughts, CRLF could inhabit the brackish margins of coastal lagoons. Generations of CRLF depended on the full complex of ever-changing floodplain habitats, flood-prone habitats, and near-tidal habitats that was only available at the scale of whole valleys. The complex habitat mosaic that characterized the native landscape at Point Reyes is typical of coastal watersheds throughout the historical range of CRLF.

8.4 Restoration Design Considerations

It is assumed that any restoration efforts will incorporate natural hydro-geomorphic processes to the full extent possible.

The future habitats for CRLF can be planned as a set of deterministic but inter-related hydro-geomorphic processes that create and sustain a mosaic of aquatic and semi-aquatic features that function as CRLF habitat for breeding, dispersal, sheltering, and so forth. Each of the major watersheds in the study area will provide a slightly different mosaic of the same hydro-geomorphic features. Once the mosaic for a watershed has been planned, then its possible response to a range of climate change scenarios might be examined, at least as a set of descriptive what-ifs, to explore how the management alternatives might be modified to accommodate climate change.

A few land management alternatives present themselves as bookends for the range of possibilities. One obvious alternative is to do nothing. The dams will be destroyed through more or less natural processes at rates determined by climate and weather. Some amount of CRLF habitat will remain as coastal lagoons, in-stream pools, the bottoms of excavated impoundments, and perhaps depressional or slope wetlands where valley bottoms and wet hillsides intersect. There will need to be assurances that dam failure will not cause unacceptable economic or ecological harm. It may be necessary to maintain some dams and not others.

Another alternative is to do everything. It will be useful to imagine what this alternative might entail. A plan to restore the whole dynamic mosaic of CRLF habitat in the watershed context might involve the following considerations.

- Restoration opportunities and constraints should be assessed for each major watershed in the study area, including Home Ranch, Limantour, Glenbrook, and Muddy Hollow. A survey of additional valleys within the Wilderness should be considered. The assessment might begin with a diagnosis of impoundment condition as initiated by this report. The existing and likely future downstream influences of impoundments will need to be considered in enough detail to determine whether the impoundments should be removed, repaired, or only monitored. Of special interest will be the existing effects of impoundments on channel incision and aggradation, and the potential channel responses if dams fail.

- In almost every watershed, the historical alluvial fans are bisected and the mainstem channel is entrenched. The restoration of sediment storage and groundwater recharge functions of alluvial fans by filling their channels should be considered as a way to reduce peak flows and to recharge the shallow aquifers that mainstem base flows.

- Restoration of the mainstem channels should focus on arresting incision and restoring the valley floors as broad, active floodplains. Each of the major creeks has been largely removed from the middle of its valley and restricted to the valley edge. Within the entrenched channels, the flood plains are usually narrow benches. Perhaps sedimentation in selected reaches of some existing channels can be encouraged through input of large woody debris that fosters natural depositional processes, and the remaining floodplains or valley flats can function as shaded, off-channel wetland habitat. They could also be designed to mimic natural channel remnants. They might eventually fill with detritus, but in the interim, they might provide breeding habitat for CRLF.

- Once a broad valley floor floodplain is restored, and the water table rises to the ground surface or nearly so, shallow excavations into the water table can be created as sustainable breeding habitat that does not requires dams or ongoing maintenance. This approach to habitat creation will be easiest in the areas of groundwater saturation at the bottoms of the valleys, above where the valleys begin to transition into the intertidal zone. This approach would have to consider the effects of sea level rise on the optimal locations for the excavations.

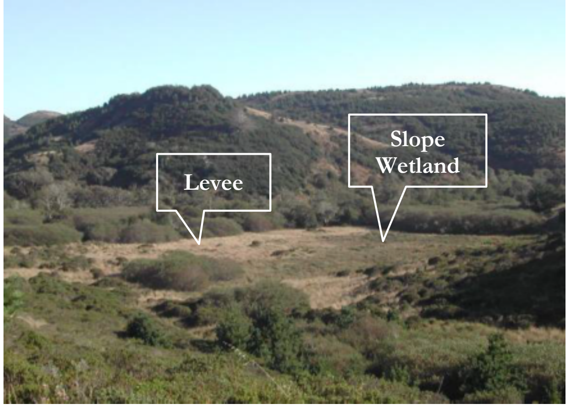
- The restoration or creation of lagoons large or small might be considered. They will tend to form on their own, however, where fetch, sediment supply, and wave regimes are suitable. The historical T-sheets can be used to guide the selection of places where lagoons have existed and are therefore likely to support lagoons in the future.

Whatever actions are taken on behalf of CRLF must not be planned in isolation from other ecological objectives. It will be helpful in the long run to use CRLF as one species in a set of focal species, each of which requires a different set of habitats subject to different geomorphic controls. Once a plan is implemented, then a monitoring program will be needed to track progress toward the plan's objectives. Having clear, quantitative restoration objectives is essential; the meaning of success should be clear from the start.

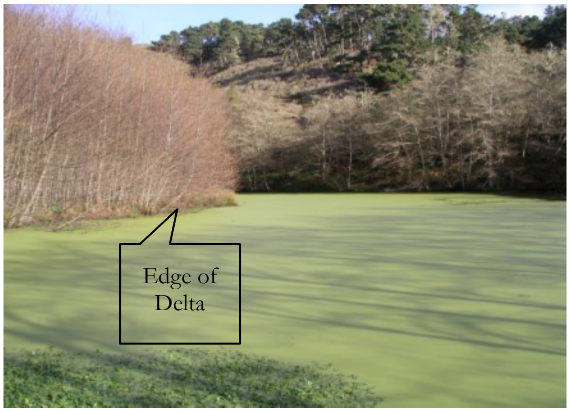
P-071: Wave erosion along interior dam face.

P-070: Headcut up spillway into exterior dam face.

P-066: Avulsion of Home Ranch Creek forming new wetlands.



P-058c: Slope wetland forming behind natural levee along Muddy Hollow Creek..



P-054: Alders on delta forming from in-fill at upstream end of impoundment.

PC-11: Natural seasonal wetland in topographic depression on ridge top. Also see Figure 18.

P-187: Coastal lagoon behind berm built of sand and debris deposited by wind and waves along estero shoreline.

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Appendix 1: Study Site Minimum Age

Date of the earliest map or aerial photo that shows a site determines its minimum age.
x = site outside scope of map or photo; **no** = site within scope but not shown **yes** = site shown
Nat = natural site

Site ID	1918 Quad	1942 Photos	1952-54 photos, quads	1958-60 photos, quads	1984 photos	1995 photos	minimum age	certainty low= 1 mid=2 high=3
P-006		x	no	x	yes	yes	20	3
P-029		x	x	x	yes	yes	45	1
P-030		no	x	x	yes	yes	45	1
P-031		x	x	x	yes	yes	45	1
P-032		x	x	x	yes	yes	45	2
P-042		x	x	x	x	yes	45	2
P-043		x	x	x	x	yes	45	2
P-044		x	x	x	x	yes	45	2
P-045		x	x	x	x	yes	45	2
P-046		x	x	x	x	yes	45	2
P-047		x	Nat	x	x	yes	45	2
P-048		x	x	x	yes	yes	45	2
P-050		yes	no	x	yes	yes	45	3
P-051		x	no	x	yes	yes	45	3
P-052		x	no	x	yes	yes	45	3
P-053		x	no	x	yes	yes	45	3
P-054		no	x	x	yes	yes	45	2
P-058b		x	x	no	yes	yes	50	2
P-058c		yes	yes	x	yes	yes	65	3
P-0S1		x	x	x	yes	yes	20	1
P-059		no	no	no	yes	yes	45	3
P-060		no	no	no	yes	yes	45	3
P-061		no	no	no	yes	yes	45	3
P-070		no	no	x	x	yes	45	3
P-071		no	no	x	x	yes	20	3
P-118		no	no	no	yes	yes	20	3
P-118b		yes	yes	yes	yes	yes	65	3
P-119		no	no	x	yes	yes	45	3
P-120		x	no	yes	yes	yes	45	3
P-121		no	no	no	yes	yes	45	3
P-125		x	no	x	yes	yes	45	2
P-126		x	no	x	yes	yes	45	3
P-128		x	no	no	yes	yes	20	3
P-129		x	x	x	yes	yes	45	2
P-130		x	x	x	yes	yes	45	2

Appendix 1 continued

Pond ID	1918 Quad	1942 Photos	1952-54 photos, quads	1958-60 photos, quads	1984 photos	1995 photos	minimum age	certainty low= 1 mid=2 high=3
P-131		no	x	x	yes	yes	45	2
P-132		no	x	x	yes	yes	20	1
P-168	Nat	x	x	x	yes	yes	20	1
P-172	Nat	yes	x	x	x	yes	65	3
P-180		no	no	x	yes	yes	45	3
P-181		x	no	x	yes	yes	45	2
P-185		no	no	yes	x	yes	45	2
P-186		yes	yes	yes	x	yes	45	2
P-187		wild	wild	yes	x	yes	45	3
P-188		x	x	yes	x	yes	65	2
P-311		x	x	x	yes	yes	45	3
P-315		yes	yes	no	yes	yes	65	3
P-318		no	no	yes	yes	yes	45	3
P-323		no	x	x	yes	yes	65	3
P-324		no	x	x	yes	yes	45	1
P-325		yes	x	x	yes	yes	65	3
P-326		wild	x	x	yes	yes	65	3
P-331		no	x	x	yes	yes	45	2
P-354		no	no	yes	yes	yes	45	3
P-356		x	x	x	yes	yes	20	1
P-357		x	x	x	yes	yes	20	1
P-555		x	no	x	yes	yes	45	2
P-574		x	x	x	no	yes	45	3
PC 1		yes	x	yes	yes	yes	65	3
PC 3		x	x	x	yes	yes	45	1
PC 4		x	x	x	no	yes	45	1
PC 5		x	x	x	no	yes	45	1
PC 6b		no	no	x	yes	yes	45	2
PC 7		x	x	yes	yes	yes	45	1
PC 8		no	no	no	yes	yes	65	2
PC 11		x	x	x	no	yes	65	2
PC 12		x	no	x	no	yes	45	2
PC 13		no	no	no	no	yes	45	3
PC 14		no	no	no	yes	yes	20	3
PC 16		no	no	no	yes	yes	20	3
PC 17		no	no	no	yes	yes	20	3
PC 99*		no	no	yes	yes	yes	45	3
PC 100		x	x	x	yes	yes	65	2

Appendix 2 Part A:

Indicators Developed to Classify Study Sites and Assess Their Geomorphic Condition

Indicator for Site Classification	
Pond Type	Sites types were coded as: (1) natural; (2) excavated and having no dam or having a minimal berm; (3) excavated and having a dam; or (4) not excavated and having a dam.
Geomorphic Setting	Sites were coded as occurring at:: (1) ridge top; (2) colluvial hollow (3) upper hillslope; (4) mid slope mainstream or tributary; (5) base of tributary or alluvial fan; (6) upper or middle mainstream valley or (7) mainstream valley bottom.
Site Minimum Age	Unnatural sites were coded as being: (1) at least 20 years old; (2) at least 45-50 years old; or (3) at least 65 years old.
Grazing Status	Sites were coded as (based on maps of grazed lands): (1) not grazed; or (2) grazed.
Inter-site Connectivity	Sites were coded as being: (1) within 1000 feet downstream of another site; (2) within 1000 feet upstream of another site; (3) more than 1000 feet upstream or downstream from another site. Note: For mid to lower mainstream valley sites, a distance of 2000 ft was used.
Breach Status	Sites were coded as being: (1) not breached and there is no past or present breach; (2) partially breached through the dam or spillway; or (3) fully breached to the dam base through the dam or spillway.
Indicators of Site Physical Condition	
Dam Height above Ground	Dam height above the ground immediately downstream of the middle of the dam was surveyed in feet with a hand-held level and survey rod.
Dam Height above Water	Dam height above the water level was surveyed in feet with a hand-held level and survey rod (these data were only used to help assess spillway condition).
Dam Height above Spillway	Dam height above the spillway midline was measured in feet with a hand-held level and a survey rod.
Dam Ht above Partial Breach	In the case of dams that were partially breached, dam height above the bottom of the breach was measured in feet with a survey tape or a hand-held level and a survey rod.
Dam Average Top Width	Measures of dam width were made with a survey tape at three places and averaged.
Dam Minimum Top Width	The narrowest place on the dam top was measure with a survey tape.
Indicators of Site Physical Context	
Historical Drainage Area	Historical drainage area of a site refers to the entire watershed upstream of the site, including areas draining to other, upstream sites. Drainage area was measured in acres on 1:2400 scale USGS quadrangles.
Modified Drainage Area	Modified drainage area of a site refers to the historical drainage area minus the potions draining to other sites. Drainage area was measured in acres on 1:2400 scale USGS quadrangles.
Upstream Channel Condition	Sites were coded as having: (1) no channel; (2) multiple distributary channels (may be discontinuous); or (3) single-thread channel (may be discontinuous).

Appendix 2A continued

Downstream Channel Condition	Sites were coded as having: (1) no channel (can have dispersive saturated overland flow); (2) multiple distributary channels (may be discontinuous); or (3) single-thread channel (can have one per tributary drainage entering site).
Sediment Supply	Based on the field and photographic evidence of delta formation or shoaling within a sites, sediment supplies were coded as: (1) minimal; (2)moderate (deltas in total comprise < 25% of original site surface area); or (3) major (deltas comprise > 25% of original site area).
Minimum Dam Width Class	Minimum dam width was coded as: (1) 0 ft (0.1 was used to represent zero); (2) 0.5-2 ft; (3) 2.5-4 ft; (4) 4-8 ft; (5) 8-12 ft; (6) 12-15 ft; (7) 15-20 ft; (8) 20-30 ft; or (9) > 30 ft.
Dam Seepage Class	Dam seepage was coded as: (4) none; (3) along dam base (often associated with emergent wetland); (2) on dam face causing deep scallops and/or slumps and gullies; or (1) along dam base and on its face (a combination of classes 1 and 2).
Dam Face Erosion Class	Erosion of the downstream dam face due to processes other than seepage, such as cattle trammeling, dam overflows or other runoff, etc. was coded as: (5) none; (4) minor (small active erosion or large old features stabilized by vegetation); (3) major (large active scallops, slumps, or gullies). (2) dam partially breached; or (1) dam fully breached
Interior Wave Class	Dam wave erosion of the upstream dam face was coded as: (3) none; (2) minor (small active scallops or large old features stabilized by vegetation); or (1) major (large active scallops and/or bank slumping).
Exterior Wave Class	Dam erosion due to intertidal wave cuts was coded as: (3) none; (2) minor (small active scallops or large old features stabilized by vegetation); or (1) major (large active scallops and/or bank slumping).
Spillway Condition Class	For sites with dams, the condition of the spillway was coded as: (8) no spillway; (7) spillway abandoned due to breach in dam (but was previously incising); (6) spillway has always been stable; (5) spillway was incising but has stabilized; (4) spillway incising but breach is not imminent; (3) spillway incising and breach is imminent; (2) spillway partly breached (water level lowered but some water impounded); or (1) spillway totally breached (some impoundment may still exist due to original excavation intercepting groundwater below base level of dam).
Potential Water Head	To help assess the risk to downstream habitat represented by a breach, the potential water head was assessed as the distance from the dam base to the maximum possible water height (to spillway or partial breach): (0.1) < 2 ft; (1) 2-4 ft; (2) 4-6 ft; or (4) 6-10 ft. 5 = 10 – 15 ft 6 = 15 – 25 ft 7 = > 25 ft

Appendix 2 Part B:

Indicators of CRLF Habitat Condition

Indicator	Site Classifications
Wetted Perimeter Class	The wetted perimeter of each site was measured based on site reconnaissance and recent aerial photography using Google Earth Pro. All measurements were codes as: 0 = 0.0 – 0.1 ft 1 = 0.11 – 100 ft 2 = 101 – 200 ft 3 = 201 – 500 ft- 1000t 5 > 5000 ft.
Adjacent Vegetation Class	Dominant plant cover type within a 50-m (150 ft) zone around each study site was visually classified as: 1 = dominated by sparse cover of grazed coastal grasslands 2 = dominated by dense coastal grasslands with scant coastal scrub 3 = dominated by coastal scrubs with mixed with coastal grasslands 4 = dominated by dense coastal scrub with or without direct connection to riparian corridor
Aquatic Vegetation Class	Percent cover of aquatic vegetation within 5m of the shoreline was estimated from site reconnaissance, on-site photography and recent aerial photography and codes as: 1 = scant cover (< 10%) 2 = moderately abundant and diverse cover (11-50%) 3 = abundant and diverse plant cover (>50%)
Hydroperiod Class	Hydroperiod as assessed as minimum summer time water depth and classified as 1 = < 31 cm 2 = 31 – 100 cm 3 = > 100 cm

Appendix 3

Summarized Field Descriptions of Individual Study Sites
A photographic record of the study sites is available under separate cover at the PRNS

Site P-006
This site is series of slow pools along stream course that crosses the bottom of the saturated valley before entering tidal marsh. Pools vary in salinity and thus in plant composition. There are channel scars into which groundwater emerges, at least during wet season. Some pools 3 ft deep and densely vegetated with submergent vegetation. Fresher pools support cattails; brackish pools are surrounded by salt grass and pickleweed. Sub-adult CRLF observed in brackish pools.

Site P-029
This is a round impoundment near Mt Vision Rd with small dam; 1.5 ft spillway downcutting in past but now stopped and vegetation is prograding to new (lower) high water line; gully downstream has headcut 3 ft high but 60 ft below dam and not very active - large granite boulders stopping headcut at this time. Deep badger burrows in dam face not a threat to dam.

Site P-030
There are wave-cut scallops on impoundment side of dam but otherwise dam in good shape.

Site P-031
Past wave cuts abundant and some still active. Spillway has active headcut 2 ft deep within 30 ft of dam. Valley steepens rapidly below dam.

Site P-032
This is a small impoundment behind sedge dam upstream of impoundment P-032. Slight headcut 0.5 ft deep in downstream channel is 11 ft downstream of water surface - no big risk of breaching. Concrete dam at zone of water input through seeps helps to prevent sediment input.

Site P-042
Road is on dam with foot bridge across spillway. Spillway has active headcut 5 ft deep through shale starting 3 ft downstream of bridge, near edge of dam face. Dam face has three major cattle trails cut into it, reducing its width from about 15 ft to 12 ft, but these not threatening dam at this time. There are minor wave cuts on impoundment side of dam. Site is divided cross-wise by berm that is fully vegetated with forbes and reduces fetch. This berm may have been an earlier dam at the upper tidal influence. Inflow over old fan not active. Outflow from spillway headcut leads into high tidal marsh.

Site P-043
Lower impoundment as shown on USGS quad is gone due to intertidal wave cutting. For impoundment P-043, dam face is scalloped with 2 ft deep cuts, also on north shoreline. Cattle trampling creates topographic relief (benches) that have become vegetated providing good cover. Dam partially breached due to past spillway downcutting. An abandoned 2 ft CMP is now 3 ft above spillway. Spillway is still cutting down and widening through shale - now 10.5 ft wide and 3 ft deeper than original depth. Active headcut in spillway 0.4 ft deep has reached dam centerline. Inflow channels historically gullied above old fan. Outflow channels meander through tidal marsh with 3.2 ft deep nick point near tidal-fluvial interface.

Site P-044
Evidence of cattle damage including trail cutting on dam face, multiple trails serving as inflow distributaries above impoundment, and trampling of banks. Trails across dam not yet threatening dam integrity, however, and there is no major seepage or critical narrowing. Spillway steepens across dam centerline with 1 ft active headcut at dam face and another 1 ft cut half down the dam face. This leads to short channel with another 3.5 ft headcut, and yet another 1 ft cut below that, leading to fan of impoundment P-045. Dam stable at this time.

Site P-045
Dam and spillway are in good shape. Channel below spillway has 2 ft headcut 30 ft below dam leading to wet meadow that lacks well-defined channel. Dam face is bare and subject to dry ravel but not threatened. Cattle trampling of impoundment margins but no effect on dam.

Site P-046
Dam threatened by combination of wave cutting dam face on impoundment side plus cattle trails across dam plus seepage at base of dam face.

Site P-047
Site exists where a natural perched wetland used to exist. Dam has recently been repaired and extended laterally. Some seepage in SE margin into remnant of natural wetland.

Site P-048
Small dam with moderate cattle trails across dam at each end but these are not deep and not threatening the dam at this time. Dam seems to have been maintained recently. Spillway has 3 ft deep but seemingly stable nick point downstream of dam and at least 10 ft from high water line and therefore not a significant threat to the dam at this time.

Site P-050
This is a large impoundment behind dam with road. Original dam seems to have been raised about 2.5 ft and widened but supports alder forest on both sides now. A 4 ft CMP in good shape leads to rip-rapped spillway at downstream face of dam that also is in good shape. Below rip-rap the channel is incised as much as 8 ft but headcut controlled so far by large rip-rap. Inflow comes from two tributaries that have built and continue to build a large delta that supports healthy alder forest. Upstream channel is entrenched into upper part of fan and then braids out downstream over fan front with much emergent monocots. At least 7 sub-adult CRLF seen moving upstream in channels in delta. Two seen in "tree fall" holes on delta.

Site P-051
Spillway is 3 ft CMP with 13 ft outflow gully actively cutting into dam face. Gully is 15 ft deep below dam top. Cattle trails cut both sides of dam reducing its width from about 40 ft to 13 ft. But seepage is minor. Historical gullying of inflow channel has built large fan that has reduced impoundment size by half. Fan is still growing. Outflow channel also has fan of material from spillway cut. This fan leads into larger P-181.

Site P-052
Spillway has headcut partially through dam. It has newer, active 3 ft headcut just downstream of dam. At least partial breach likely soon. Previous gullying above the impoundment caused delta but gullying has mostly stopped and delta is not very active.

Site P-053
Spillway in chert bedrock that leads to slightly incised channel that then spreads out into wetland below dam. Dam has been maintained so there is no evidence of seepage or scalloping of face, and any evidence of wave cuts is old and well vegetated now. Inflow channel is diffuse immediately above impoundment but incised as gully starting 100 ft above impoundment margin. A large tadpole, perhaps CRLF, seen at dam shoreline.

Site P-054
Dam was previously breached by spillway down-cut. Dam now forested with alders growing to the "new" lower waterline. No wave erosion. No seepage except where dam abuts broad saturated wet meadow. Active “new” headcut is about 10 ft deep and only about 3 ft from dam centerline, but is now in bedrock that may slow incision. Large delta at head of impoundment has various channel scars with water. Abundant evidence of deer kills plus lion tracks. Fallen alders with uptilted root bowls leave declivities full of water. Delta has a circa 1992 alder forest closer to waterline plus a 1982 forest farther back. Delta sediment source is probably upstream landslides. Channel has incised 7 ft into mid delta and 11 ft into upper delta. Channel has formed on delta along west side of impoundment such that impoundment is essentially off-channel habitat (until spillway headcut reaches impoundment waterline).

Site P-058b
Dam adjoins tidal marsh but at low-energy shoreline (way up estuary) such that there is no intertidal wave cuts. Spillway has incised below dam but in minor way with no threaten the dam.

Site P-058c
Natural, seasonal, wet meadow adjacent to Muddy Hollow Creek. Some historical gullying above the meadow along old road and on hillside that helped build wet fan but not active now. No breeding pools for CRLF.

Site P-059
Dam has deep scallops on face due to seepage and piping, plus wave cuts on impoundment side of face that together reduce top width from 8.5 ft to 5 ft. Spillway has gully 3 ft deep and 7 ft wide that is within 3 ft of breaching. Dam will either breach due to overflow or face failure or due to spillway incision, or both. This is the upper impoundment in a chain of impoundments.

Site P-060
Dam wave cut is old with alders at waterline leaning over impoundment as if undercut. Spillway has gully 4 ft deep and 7 ft wide that turns into falls over bedrock section just downstream of dam but its headward cut toward impoundment probably slow due to bedrock control, but bedrock is erodable Monterey Shale so headcut will likely proceed. There is moderate seepage with scallops on dam face. But this is a very broad dam.

Site P-061
Site breached due to spillway incision. Shallow impoundment le ft with *Typha* but unlikely to last as CRLF breeding habitat throughout the year. Fan below breach is now wet meadow. In flow channel has incised through old shoreline into gully 4 ft deep that is starting to headcut up-valley, and this will increase sediment supply to little remaining impoundment. This is the lower impoundment in a chain of impoundments.

Site P-070
Dam breached in two ways: spillway incised but then filled with debris while delta formed causing impoundment to over-top and mostly cut dam where intertidal scalloping had also begun. There is also wave cut erosion from estuary. Large delta formed due to gullying above the impoundment but gully is stable now and delta is not active. Downstream channel is shallow over high, consolidated mud flats.

Site P-071
Dam and spillway in good shape except dam face subject to intertidal wave cut. Upstream channel incised 3 ft starting about 50 ft upstream of impoundment. Cattle trampling impoundment margins and both sides of dam face.

Site P-118a
Seep wetland associated with road berm but no dam. No distinct impoundment although some cattails are present.

Site 118b
This is essentially a wet meadow with tall caryx and Typha leading to Distichlis and pickleweed at the fluvial-tidal interface with brackish influences due to extreme high tide. There is minimal distinct impounding and probably insufficient topographic relief intercepting the groundwater to provide breeding habitat for CRLF. This is the transition from fluvial flow and groundwater emergence with tidal submergence across the broad bottom of a large valley. If there were channel scars or other declivities at least 2 ft deep into the ground, then this area could probably support CRLF breeding.

Site P-119
Dam was breached due to overtopping plus gullying of dam face due to seepage. Spillway exists and was incising slightly at dam midline at one time, and leads to larger gully downstream of dam, but spillway was abandoned when breaching happened though dam face. Gully above is no longer active and is densely vegetated. Further breaching is possible but perennial impoundment will remain due to original excavation to at least 2-3 ft below summertime groundwater level.

Site P-120
Dam partially breached by seepage-caused cutting of dam face matched by wave cutting on impoundment side at low point in road across dam. Problem probably exacerbated by overtopping due to absence of formal spillway. Breaching has stopped for now probably due to compaction of dam under road across the dam. But headcut into downstream dam face is 7 ft, and 3.6 ft into dam on impoundment side. Broad vegetated bench has been created by elk activity at new waterline.

Site P-121
Dam breached due to seepage causing incision and scalloping on dam face plus lesser amount of wind-wave cutting on impoundment side. Cattle trails might also have had effects. Downcutting below spillway also started to happen but was replaced by cutting of face due to seepage. Breach is to water table level in original excavation which is deep enough below groundwater level to sustain perennial habitat.

Site P-125
Dam has scallops 3 ft deep on face but these are densely vegetated with shrubs and apparently stable. Seepage has caused a 1.5 ft cut all along the base of the dam. 1.5 ft headcut in spillway in shale is still 10 ft from midline of dam. Historical erosion evident as vegetated gullies above the impoundment plus an old delta that is barely active now.

Site P-126
Dam has very modest spillway 1 ft deep that mainly just leads to channel overtopping during storm events. This plus seepage has caused gully on dam face leading to piping toward wave cut scallop on impoundment side. When the channel enlarges and connects to scallop, downcutting through dam will commence.

Site P-129
Dam is in danger of failing. 2 ft diameter CMP drain that used to limit water level is clogged. Spillway below culvert has12 ft deep active gully cutting 3.2 ft into dam leaving just 5.2 ft of dam top width. With culvert clogged, overtopping possible. This is an upstream impoundment in chain of impoundments.

Site P-130
Dam face with extensive seeps, piping, gullying due to piping. Deep wave cuts have created benches on impoundment side of dam that are now vegetated by cattails. Gullying plus wave cuts have cut almost all the way across the dam top. Breaching through dam face seems very likely. There is a gully on spillway downstream of dam but it seems stable now or is slowly cutting headward.

Site P-131
Dam is fully breached in middle of dam due to gullying of dam face caused by piping and seepage. Wave cutting on impoundment side of dam not very evident. There is a major gully 10 ft deep on spillway channel below dam but spillway is abandoned. Two abandoned culverts (one above the other) used to drain impoundment. Upper one is 3.5 ft below dam top (just like spillway) and abandoned; lower one is about 10 ft below dam top, both are above water level. Further breaching possible due to headward cutting of channel through existing breach. This is the lower impoundment in a chain of impoundments. Remaining impoundment is due to groundwater input into bottom of original excavation.

Site P-132
Except for *Apollonian* burrows on dam face, impoundment and dam are in great shape.

Site P-168
There is a long, low arcuate dam across the valley bottom. A cattle fence bisects the dam and cattle moving along the fence have cut trails across dam that provide channels for overflow and thus threaten to breach the dam. Freshwater marshland below dam is about 1.5 ft above adjoining high tidal marsh, and there is no evidence of intertidal wave cuts on dam. It looks as though a substantial amount of the impoundment has been filled with sediment.

Site P-172
Dam threatened by combination of intertidal wave cutting 1.5 ft into base of dam face plus cattle trails cutting into both dam faces. Spillway okay for now but has 5 ft active headcut into shale at

dam face leading to fan building over tidal marsh downstream of spillway. Spillway headcut into dam likely. Gullied road leads to upper margin of impoundment with 24in CMP under road delivering sediment to active fan. Three sub-adult CRLF near 10 ppt salinity pool at edge of tidal marsh below dam, where seepage from dam meets upper intertidal zone. Salinity measured with refract meter.

Site P-180

Dam subject to intertidal wave cuts 3 ft deep plus less significant wave cuts on impoundment side. Seepage along dam base and at mid-slope of face and from intertidal wave cuts. Spillway has 2.5 ft deep headcut through most of dam reaching within 2 ft of high water line of impoundment. There may be culvert about 5 ft below dam top but vegetation too thick to tell. Incision also on both dam faces from runoff from road that crosses the dam, but these incisions not yet meeting each other at dam top, due to road compaction.

Site P-181

Dam built on old tidal marsh or mud flat - weight of dam has caused large mud wave that protects dam from intertidal wave attack. Gully erosion from culvert entering impoundment on North side and some minor bank erosion given large size of "impoundment." Mud wave provides significant added support to dam and also provides grade control to spillway, which fans out over marsh.

Site P-185

Dam almost completely breached due to combination of spillway incision and scalloping of dam face. Base of dam is attacked by intertidal waves during high tide that contributes to scalloping of dam face. The spillway is at risk of erosion even though past erosion seems to have sowed. Tide does not yet enter impoundment, which is shallow. Channel downstream has 2.5 ft headcut in tidal reach 40 ft below dam - ebb tide pours over this nick point. Tidal marsh is returning to historical upland-tidal ecotone due to residual salts behind historical tidal wrack of logs. Further breaching is likely as spillway continues to incise due to fluvial outflow.

Site P-186

Wind-wave cut scallops are 4 ft deep on impoundment side of dam. Dam gouges caused by seepage 1.5 ft deep at some places along dam base. Spillway has cut down 1.5 ft in the past, but is not now actively cutting. Two gullies have evolved from inboard ditch of adjacent road but none of this sediment reaches the impoundment. This is the upper impoundment in chain of impoundments.

Site P-187

This impoundment was originally man-made but the spillway breached. It is now more or less a natural impoundment formed behind a broad intertidal berm built from vegetated wrack that traps sand along high-energy intertidal shoreline. Berm is broad but sometimes gets breached by storm waves and then reforms. This is now considered threatened. Water in impoundment comes from seepage from upstream impoundment P-188 but is also marginally brackish (1 ppt) at depth. No CRLF seen but a large splash heard.

Site P-188

Dam was breached by over-topping on dam and now this impoundment is part of the natural P-187. Middle impoundment in chain of impoundments.

Site P-311
Dam breached due to spillway incision which is stable at this time. Large gully below historical impoundment margin supplied much sediment at that time. When impoundment was larger, wave erosion and seepage of dam face was occurring but not now.

Site P-315
This is a small impoundment with abundant vegetation created by excavating and damming a spring and slope wetland that continues downslope from the little dam. There is no spillway but a 4in diameter PVC pipe that is apparently clogged but used to provide some drainage. Much organic muck has accumulated in the impoundment.

Site P-318
This impoundment no longer exists. According to the maps, it was in a ridge crest saddle near a water tank. But there is no evidence of it at this time.

Site P-323
Small natural seasonal wetland at end of Mt. Vision Rd. Holds about 1.5' of water max and dries out during CRLF breeding season. Good for Hyla.

Site P-324
Spillway has incised 1.5 ft – 2 ft through dam, lowering the water level that much and leaving a bare bathtub ring effect. Spillway has active 4 ft headcut downstream of dam. Site may be 18in deep at this time but breaching due to spillway failure likely.

Site P-325
Spillway has active gully head 5 ft deep and only 8 ft from water edge. Breaching due to spillway incision likely.

Site P-326
Natural seasonal wetland with abundant *Hyla* but hydroperiod is too short for CRLF breeding.

Site P-331
The spillway is working well, and flows into a 1.5 ft diameter corrugated metal pipe at Mt Vision Rd. The roadway may serve to buttress the dam.

Site P-354
This impoundment is not accessible due to extremely dense re-growth of Bishop pines and coastal scrub after the Vision Fire. All data were derived from the interpretation of maps and aerial photos.

Site P-356
Dam has been recently repaired or maintained. There is evidence of past seepage and breakdown of both faces of dam by cattle, but repairs are comprehensive. There is a 2-3 ft headcut far below spillway that is not a threat. Bank erosion by cattle evident but not a threat to dam.

Site P-357
Small scour pool from 18in culvert that runs under road. Pool depth is about 1 ft. Flow is about 3 gpm. Very little cover.

Site P-555
Site is excavated into valley floor next to ranch complex. Water is provided by a garden hose.

Site P-574
Site is a small excavation below natural seep at valley edge. There is much cattle impact. No spillway but a partially smashed 1 ft CMP provides some drainage. Site is filling with sediment from cattle trampling. Flow is controlled by spring and overflow unlikely. There is an old concrete spring box at upstream end.

Site S-1
This impoundment created by damming flow from spring that used to be enclosed but now is fully accessible to cattle, which have extensively trampled the impoundment and its margins, plus cut trails into both faces on dam, at both ends and in the middle. Dam gets overtopped at the middle cattle trail. There is an active 3 ft deep headcut in gully above the spring. Spillway leads to 1 ft deep pools just below dam that are heavily trampled by cattle.

Site PC-1
There is a wooden spring box in old exclosure in middle of gentle zero-order swale near ridge top below Mt Vision Rd; mostly natural spring but some road runoff (6" PVC pipe drains inboard ditch). Site in box is small (9 ft x 6 ft) and secure. Channel downstream has 2.2 ft nick point 300 ft below spring box that is not a threat.

Site PC-3
Small perennial impoundment created by concrete wall 8' long and about 4' high across small seep or spring. Site may have been covered with wood at one time.

Site PC-5
Old sediment-filled impoundment (no impoundment le ft) with very deep (11 ft) gully that has cut through old dam site and is now cutting headward into sediment that was deposited behind the dam. Sediment source was possibly upstream gullying or sliding during 1982 storm event. Scenario is that landsliding filled impoundment and runoff went over dam, cut a gully that then eroded headward through dam to begin releasing stored sediment.

Site PC-6b
This is an unusual case where there is a dam but no water behind it. Seems that site was mistaken as a spring but no flow available. Some direct rainfall might impoundment behind dam very temporarily. It's an unbreached dam without an impoundment.

Site PC-7
Dam blown out by Muddy Hollow Creek probably due to landsliding upstream during 1982 storm event that filled impoundment with sediment, causing it to overtop and cut through dam. Spillway not breached. Breach through dam is still incising, as is the whole creek through the deposited sediments behind the dam. Laurel Collins has additional notes from her fire study on file at Point Reyes USNPS Headquarters.

Site PC-8
This used to be an area of standing water behind road fill that is now filled with *Typha*. And is not breeding habitat for CRLF.

Site PC-11
Natural seasonal wetland on drainage divide with significant cattle trampling and hydroperiod probably too short for CRLF breeding.

Site PC-12
Dam existed within intertidal zone and was breached by overtopping plus weakened by wave erosion from both sides, and impoundment has since been restored to full tidal action. Upstream (headward) reaches of intertidal zone and its interface with fluvial input is addressed as impoundment P-118b.

Site PC-13
Site has nearly filled with sandy sediment from upstream. There was a breach, and yet the channel continues to aggrade and flow over and past the historical impoundment and formed a broad wet Caryx meadow below the old dam (the meadow is addressed as site P-118b). It is unlikely that this breached impoundment includes any perennial habitat although some pools in channel may be deep enough to qualify as CRLF breeding habitat during some years.

Site PC-14
Small excavated impoundment has small dam near transition from ridge crest to hillslope with no spillway and no apparent threats to dam. Elk and deer sign abundant. California Newts in impoundment.

Site PC-16
This is a small excavated impoundment with a small dam at 1st-oder inflection below ridge line. Historical erosion on side slopes related to grazing now stable. No spillway but no evidence of any threats to dam.

Site PC-17
Totally blown-out dam with perennial stream flowing through breach through dam face. Seems as if sediment filled the impoundment which then overtopped and breached. 24 in CMP found 700m downstream probably came from this dam. Alders on sediment in-fill behind old dam have mean DBH of 0.74 ft suggesting fill happened in 1982 El Nino storms, perhaps due to upstream landsliding.

Site PC-99
This is a scour pool with water 2 ft deep at end of large, well-vegetated old gully that was caused by past grazing practices. The gully disperses onto an old fan that is now a slope wetland.

Site PC-100
Natural seasonal wetland good for *Hyla* but not deep enough or having a long enough hydroperiod for CRLF breeding. This might be natural analogue for what existed at the site of impoundment P-045 before that dam was built.

Site PC-101
Natural seasonal wetland on ridge-line saddle. Pre-fire photos show open water but now whole system is densely vegetated with sedges, pennyroyal, etc. Max depth is about 6 in, based on old algae hanging in vegetation. This wetland is clearly evident on USCS T-sheet ca 1852. Not CRLF breeding habitat.

Appendix 4

Site Suitability Model for CRLF

1.0 Rationale and Limitations

This purpose of this study was to explore possible thresholds of impoundment condition that correspond to the presence or absence of CRLF. This study was not intended to be a survey or census of CRLF, or a detailed assessment of CRLF habitat. However, the previous CRLF surveys conducted in the study area provide a basis for a cursory evaluation of the different impoundments as potential breeding habitat.

This study only pertains to the portion of the Phillip Burton Wilderness for which CRLF presence-absence data were made available by the PRNS. There is no expectation that the results pertain to any other area or any other data sets.

The evaluation is limited by the lack of CRLF population size estimates within and among the study sites. The lack of reliable population estimates precludes any correlation analysis between the conditions of sites and their level of CRLF support. However, there are abundant presence-absence data that can be used to identify possible thresholds in habitat condition that correspond to the presence of CRLF.

Presence-absence analyses are always fraught with uncertainty relating to the unsure meaning of apparent absences. CRLF can be very difficult to census, and an apparent absence of CRLF might only mean a failure to detect its presence, not that CRLF are actually absent. The quality of the data is largely determined by the experience of the surveyors and the quality of the methods they use. The dataset available for this study has the assurances of experienced people using proven methods in consistent ways. The dataset is also improved by including repeated surveys for some sites over different years and different times of year. This greatly improves the confidence in records of both the absence and the presence of CRLF.

2.0 Methods

Each site was scored with regard to fundamental factors relating to the quality of CRLF breeding habitat. Of particular concern are the amounts of plant cover within the impoundments and within a zone around them, the effective size of the impoundment as habitat, and the hydroperiod of the impoundment, meaning the timing and duration of required water depths.

The understanding of these factors in relation to CRLF breeding is not perfect. A review of the pertinent data from across the CRLF distribution reveals much variability in CRLF habitat preferences. There is agreement, however, that vegetation cover, site size, and hydroperiod are important factors. Other important factors not considered in this simple assessment include food resources, predation pressure, and landscape context. Predation may be especially important. However, the factors selected for this assessment are fundamental aspects of habitat structure that relate to the landscape position and restoration design of breeding habitat.

Based on a review of CRLF breeding habitat characteristics (see Section 5.1 of report), and based upon the reconnaissance of the study sites, and given the time and budgetary constraints of this study, the following set of basic indicators of CRLF breeding site potential was assembled.

2.1 Hydroperiod

Hydroperiod and maximum summertime water depth were inferred from breach base height and dam base height, and actual depth measurements. Boats were not used in this study, so direct measures of depth were not possible for the larger reservoirs. Many sites that were assessed in the wet season were visited again in the dry season to calibrate estimates of hydroperiod and water depth. The maximum possible wet season depths that were inferred from breach or spillway heights were adjusted for expected evaporation to account for drawdown during spring and summer. These estimates of summertime maximum depth agreed well with the measured depths in the smaller and shallower impoundments. The measured and estimated water depths were then compared between sites where CRLF had been detected, and for sites where they had not been detected, to assess possible minimum required summertime depths. Sites where CRLF were detected during this study were pooled with the detection sites for the previous surveys (Fellers and Guscio 2002, Fellers and Osbourn 2004), but only the non-detection sites from the previous surveys were used in this analysis. Since the current study was not a CRLF survey, its non-detections are not reliable. The results suggest that, all other factors notwithstanding, a minimum depth of about 30 cm for July seems to be required (Figure 16). This is a little higher than other estimated minimum depths for breeding sites in the Coast Ranges, (Reis 1999, Fellers 2005), and lower than what has been expected for the Central Valley (Hayes and Jennnings 1988). Site P-129 is the only site with an estimated summer minimum depth greater than 30 cm where no CRLF were detected. This is a deep site with abundant aquatic plant cover and in most regards seems like a suitable CRLF breeding site.

2.2 Aquatic Vegetation

The purpose of this indicator was to account for aquatic vegetation as oviposition substrate, a source of macroinvertebrate prey, and as cover for CRLF larvae and adults. Estimates of percent cover were based on field reconnaissance, oblique photos taken in the field, and recent aerial photography. Only the zone within 5m of the shoreline was considered in the cover estimates. Emergent species, submergent species, and species that form floating canopies were considered together. Dominant species were noted but no specimens were collected. Common submergent species included pondweeds (*Potamogetron* spp, especially *P. pectinatus*), and coontail (*Ceratophyllum demersum*). Common species that form floating canopies included water pennywort (*Hydrocotyle umbellata*), and water parsley (*Oenanthe* spp). Common emergent species included cattails (Typha spp), bulrush (*Scirpus acutus* or *S. californicus*), and spike rush (*Eleocharus* spp.). The data were binned into 3 classes (<10%, 11-50%, >50%). The indicator was calculated as the percent of the maximum class.

2.3 Wetted Perimeter

The wetted perimeter of each site was measured as a proxy for the amount of feeding and breeding habitat the site provides to CRLF. The underlying rationale is that the total area of a site is less important to CRLF than the amount of edge, since it provides food resources, cover, access to non-breeding habitat, filtration of materials entering the site through runoff, etc. The perimeter was measured in feet by tracing the boundary between the littoral zone of the site and the adjacent upland on recent high-resolution aerial photography (pixel resolution 1-2m) using the pen tool provided through Google Earth Pro. The perimeter lengths were then binned into 5 classes (1-100 ft, 101-200ft, 201-500ft, 501-1000ft, and >1000ft). The indicator was calculated as the percentage of the maximum class.

2.4 Adjacent Vegetation

The dominant plant community for a zone of 150ft surrounding each site was described based on field reconnaissance and oblique on-site photography. The purpose of this indicator was to assess the quality of sheltering and dispersal habitat adjacent to the potential breeding sites. There is evidence that CRLF will disperse across grasslands and other open areas (Bulger et al 2003, Fellers 2005). Yet, there is general agreement that dispersing CRLF prefer dense cover affording moist ground-level conditions contiguous with breeding sites (Rathburn et al 1993, Jennings and Hayes 1994, USFWS 2002, Fellers and Guscio 2004). Densely vegetated riparian corridors that lead to and from breeding sites may be especially advantageous to dispersing CRLF, although other plant communities that offer adequate protection from predation and desiccation can suffice (M. Jennings pers. Comm). Most CRLF disperse at night, which might reduce the risk of predation when CRLF cross open fields (Fellers and Guscio 2004).

The dominant adjacent vegetation was classified as sparse or grazed coastal grasslands, dense coastal grasslands with scant coastal scrub, an even mixture of coastal scrubs coastal grassland, or dense coastal scrub with or without direct connection to a riparian corridor. The indicator was calculated as the percentage of the maximum class.

2.5 CRLF Site Potential Index

The four basic indicators described above were integrated into one overall index of breeding site potential using the formula shown below. There was no weighting or scaling of any indicator.

CRLF Site Potential Index =
% Max. Hydroperiod Class
\+ % Max. Adjacent Vegetation Class
\+ % Max. Aquatic Vegetation Class
\+ % Max. Wetted Perimeter Class

3.0 Results and Discussion

3.1 Hydroperiod Requirement

The results of this basic assessment of impoundments as CRLF breeding habitat indicate that adult CRLF require a minimum summertime water depth of about 30 cm (See Figure 1 below). Whether this threshold of hydroperiod is a function of temperature, food resources, refuge, or simply duration of habitat availability is unknown. This threshold hydroperiod is well within the range of what has been reported for CRLF in a variety of other locations (see Section 4 of report).

3.2 Vegetation and Habitat Size

The data on vegetation and habitat size were not very useful for predicting CRLF presence. CRLF seem to use large and small impoundments, with or without much vegetation, although impoundments with CRLF tend to be larger and have more plant cover than impoundments where CRLF were not detected. No clear thresholds in plant cover or habitat size were evident.

3.3 Other Indicators to Consider in Future Assessments

A more thorough characterization of CRLF breeding sites would need to include some assessment of predation pressure or risk. Non-native predators might be especially important (USFWS 2002). Deep, perennial sites with fringing wetlands might be productive breeding sites if they are free of non-native crayfish, piscivorous fishes, mosquitofish, and bullfrogs. Thorough surveys for these predators can be expensive but useful to assess the quality of breeding habitat.

The vertical structure of lacustrine and palustrine vegetation may influence the ability of a site to support CRLF. Adult CRLF can depend on macroinvertebrates as prey (Hayes and Tennant 1985), and studies have shown that the diversity and biomass of aquatic macroinvertebrates are strongly correlated with the biomass of aquatic macrophytes in the upper 10-20cm of the water column (e.g., Kaminski and Prince 1981, Collins 1993, Gammonley and Laubhan 2002). Aquatic plant zonation, with emergent plants in the shallows bordered by submergent plants in deeper areas, indicates a long hydroperiod with stable water levels that benefit secondary production

The landscape context of an impoundment may influence its potential as a CRLF breeding site. While there is much variation in the landscape position, physiography, and surrounding vegetation of known breeding sites, the presence of multiple sites and interconnecting riparian corridors in the context of suitable sheltering habitat is a recognized landscape model for CRLF recovery (USFWS 2002, 2005). A more thorough assessment of the breeding habitat potential of impoundments might include an assessment of their landscape context, relative to this model.

3.4 Performance of the CRLF Site Potential Index.

There are no estimates of CRLF population size within or among the study sites that can be used to calibrate the indicators of site condition. The available survey data can only be used to identify sites where CRLF were detected and sites where they were not detected. While it is reasonably certain that sites with CRLF during the breeding period are breeding habitat, it can only be tenuously assumed that sites where CRLF were not detected are not breeding habitat.

The lack of detection at a site does not necessarily mean that it isn't breeding habitat. CRLF populations fluctuate, and some of their breeding sites might not be occupied every

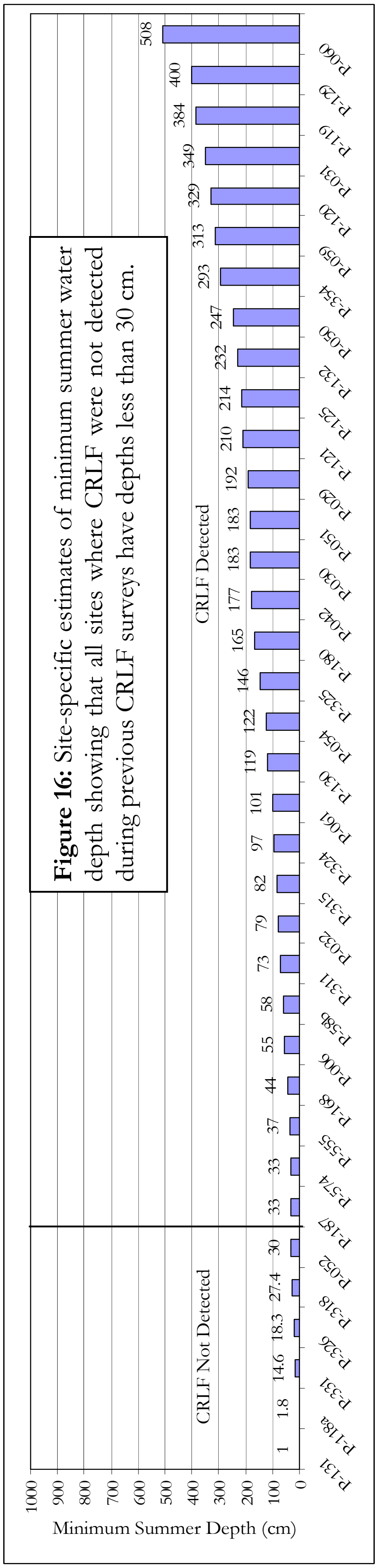

Figure 16: Site-specific estimates of minimum summer water depth showing that all sites where CRLF were not detected during previous CRLF surveys have depths less than 30 cm.

year. Many factors can interfere with the detection of CRLF. Large sites that are structurally complex, with dense emergent and riparian vegetation can be especially difficult to survey. Nocturnal surveys are much more efficacious than diurnal surveys (Fellers and Kleeman 2006), which suggests that some diurnal surveys probably fail to identify some breeding sites.

Despite these difficulties, the CRLF Site Potential Index performed well. Its performance can be assessed by using it to compare known breeding sites and non-breeding sites (Figure 2 and Table 1). The sample size for surveyed sites where CRLF has not been detected is small (n=6) compared to the sites where CRLF has been detected (n=31). A trend is evident, although the differences are not statistically significant. The population of sites where CRLF were not detected has lower scores for each indicator. The differences with regard to hydroperiod and aquatic vegetation are a little greater than the differences for perimeter length and adjacent vegetation. The difference with regard to the Index of Breeding Site Potential is significant, and suggests that any site with an index value greater than about 2.5 is likely to be a breeding site. Many sites that have not been surveyed for CRLF have the potential to be breeding sites, according to this index (Table 1).

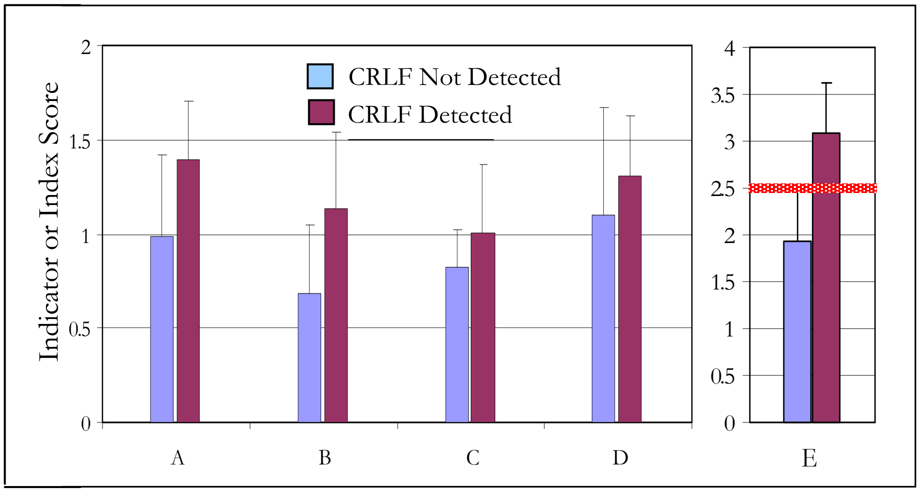

Figure 2: Comparison of sites surveyed for CRLF in terms of (A) Hydroperiod, (B) Aquatic Vegetation, (C) Perimeter Length, (D) Adjacent Vegetation, and (E) the Breeding Site Potential Index that integrates across the indicators A-D. All indicators of CRLF breeding site conditions are higher for sites where CRLF were detected than where CRLF were not detected. The indicator is variable, however, and the differences between populations of sites are not statistically significant, except for (E) the Breeding Site Potential Index. The differences are less for site perimeter length (C) and adjacent vegetation (D), suggesting that these factors are less important to CRLF, or that the indicators do not reflect the thresholds for these factors that affect CRLF. The index data suggest that any site with an index score greater than 2.5 is likely to be breeding habitat. This does not mean that other sites don't support CRLF, but that CRLF were detected at all sites having an index value greater than 2.5. There are a variety of sites where CRLF have not been surveyed that are candidate breeding sites, based on their index scores (Table 1).

Table 1: Sites where CRLF have not been detected but might be expected because the CRLF Site Potential Index is > 2.5.

Site ID	**CRLF Site Potential**
P-118b	2.56
s1	2.56
P-048	2.60
P-323	2.60
PC-11	2.60
PC-03	2.70
P-188	2.73
P-044	2.76
P-070	2.80
PC-101	2.80
P-186	2.96
P-045	3.10
P-047	3.13
P-181	3.16
P-046	3.26
P-071	3.26
P-172	3.33
PC-016	3.40
P-126	3.43
PC-014	3.60
P-043	3.66
P-053	4.00