FEASIBILITY OF ALTERNATIVES TO THE GOAT ROCK STATE BEACH JETTY FOR MANAGING LAGOON WATER SURFACE ELEVATIONS – A STUDY PLAN

Prepared for
Sonoma County Water Agency

June 30, 2011

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1. Introduction

This document, developed by ESA PWA at the request of Sonoma County Water Agency (Water Agency), describes a plan to study the effects of the Goat Rock State Beach jetty on the Russian River Estuary (Estuary). In addition, it describes the recommended approach for developing and assessing the feasibility of alternatives to the existing jetty that may help achieve target estuarine water surface elevations. As such, this study plan fulfills a portion of the Water Agency's obligations under the 2008 Biological Opinion (Biological Opinion) issued by the National Marine Fisheries Service (NMFS). The Biological Opinion directs the Water Agency to change its management of the Estuary's water surface elevations with the intent of improving juvenile salmonid habitat while minimizing flood risk.

In the Russian River Biological Opinion (Biological Opinion), NMFS has concluded that historical artificial breaching activities in the spring and summer resulted in a loss of freshwater habitat in the Estuary and that a lack of freshwater estuarine rearing habitat limits recovery of salmonid populations, particularly steelhead (NFMS, 2008). The abundance and growth rates of juvenile steelhead have been positively correlated with the freshwater habitat found in lagoons. A lagoon is created by the barrier beach blocking ocean tides and salt water from entering the Estuary. NMFS determined that salmonid estuarine habitat may be improved by managing the Estuary as a perched, freshwater lagoon. Therefore, the Biological Opinion stipulates as a Reasonable and Prudent Alternative (RPA) to existing conditions that the Estuary be managed to achieve perched lagoon conditions between May 15th and October 15th. Under target conditions, the lagoon water surface elevations would be higher than ocean water surface elevations, ideally above 7 ft NGVD[1.] To accomplish the target conditions, and to prevent lagoon water surface elevations from reaching flood stage (currently 9 ft NGVD), the Biological Opinion suggests that groundwater seepage through the barrier beach and an outlet channel incised in the beach balance riverine inflow.

Recognizing the complexity and uncertainty of managing conditions in the dynamic beach environment, the Biological Opinion stipulates that the estuarine water surface elevation RPA be managed adaptively. This means that it should be planned, implemented, and then iteratively refined based on experience gained from implementation. Part of its adaptive nature is a phased approach which starts with a limited project scope and then expands the scope only if earlier alternatives are not feasible. The first phase, which has been implemented since 2010, is limited to outlet channel management that only involves excavating a sand channel in the beach (ESA PWA, 2011). For the second phase, the Biological Opinion expands the project scope to consider alternatives to the jetty. The jetty, which is embedded in the barrier beach, may significantly affect some of the physical processes which determine lagoon water surface elevations. This document initiates planning for this second phase. The third stage further expands the project scope to include flood risk reduction measures for properties adjacent to the Estuary.

[1] NGVD=National Geodetic Vertical Datum, a fixed reference elevation adopted as a standard

The Biological Opinion calls for a study analyzing the effects of the jetty on beach permeability, sand storage and transport, flood risk, and seasonal water surface elevations in the Estuary. In drafting the study plan to address this language, we assume the following relationships between these elements. Water surface elevations are the stated objective of the Biological Opinion's Estuary Management RPA. Beach permeability, sand storage, and sand transport are physical processes which are affected by the jetty, and, in turn, affect the water surface elevations. Evaluating and quantifying these linkages will inform the development and evaluation of management alternatives for the jetty. Flood risk is not a part of the linkages between the jetty and water surface elevation management objective. Instead, increased flood risk is a potential negative impact of modifying the jetty that may limit management options.

Based on the requirements of the Biological Opinion described in the paragraph above, the goal of the study proposed in this plan is to evaluate the feasibility of modifying the Goat Rock State Beach jetty to improve the likelihood of achieving the target lagoon water surface elevations. To accomplish this goal, the study objectives include:

- Describe the extent and composition of the jetty
- Understand the jetty's effects on the physical processes which partially determine lagoon water surface elevations, including beach permeability, sand storage, and sand transport
- Evaluate the jetty's role in flood risk to property adjacent to the Estuary
- Recommend an approach for developing and analyzing jetty alternatives, such as jetty removal, partial removal, jetty notching and other uses of the jetty which may help achieve target lagoon water surface elevations

This study plan has been designed to develop an understanding of the jetty's effect on lagoon water surface elevations and barrier beach formation in the spring and summer. The study then applies this understanding to develop alternatives which modify the jetty and to assess the feasibility of these alternatives. When the study is complete, it will help inform the decision as to whether to proceed with modifications to the jetty. If modifications are undertaken, the technical analyses in the study will provide a basis for subsequent steps, including permitting and preliminary design. However, additional technical work may be required to inform potential project impacts and design features.

The Water Agency intends to meet the objectives of the Estuary RPA while staying within the constraints of existing regulatory permits and minimizing the impact to aesthetic, biological, and recreational resources of the Estuary. The Water Agency's management approach is being developed in coordination with NMFS, California Department of Fish and Game (CDFG), and California State Parks (CSP).

The next part of this study plan, Part 2, provides an overview of the existing physical setting of the jetty. Since our current understanding is not sufficient to quantify the effects of the jetty on the lagoon's water surface elevations, the remaining sections of Part 2 describe the rationale for and components of study tasks to improve understanding of the potential linkages between the jetty and lagoon water surface elevations. Part 3 then applies this understanding for developing and assessing alternatives that modify the jetty to improve the chances of achieving target water surface elevations.

2. Jetty Effects on Physical Processes

The focus of the physical process assessments is to understand the effects that the existing jetty may play in formation of a barrier beach in the spring and fall and in determining lagoon water surface elevations. These connections between the jetty, barrier beach formation, and lagoon water surface elevations need to be quantified to inform the development and evaluation of alternatives in subsequent stages. The first assessment, which will inform subsequent assessments, is the characterization of the jetty's extent and composition, as much of the jetty is hidden within the beach and poorly documented. Next, the study will look at three key processes by which the jetty may influence barrier beach formation and lagoon water surface elevations. These processes are permeability, inlet morphology, and beach morphology. In addition, the study considers the potential impact of the jetty on flood risk.

Note that morphology, or the shape of the barrier beach, is the result of and therefore includes the sand storage and transport elements called for in the Biological Opinion. We have chosen to focus the study on the morphology since ultimately the beach shape influences lagoon water surface elevations. For example, to achieve the target water levels defined in the Biological Opinion, the barrier beach morphology needs to close the inlet which connects the Estuary to the ocean. We examine the morphology at two scales, that of the inlet and the entire beach. Although they are related, these two geomorphic units are shaped by a different balance of physical forcing and are best evaluated by different analyses.

The Russian River Estuary is classified as a bar-built estuary in that its interface with the ocean is strongly defined by the barrier beach or sand berm at its mouth. The beach is subject to hydraulic forcing by both the river and ocean. Since it is comprised of mobile, well-sorted sand grains averaging 1 millimeter in diameter (EDS 2009), the beach is in constant state of motion. Much of this motion is oscillatory in nature, e.g. waves, tides, and season, and can yield little net change. However, when the balance between forcings tilts, change can be rapid, on the order of hours, and completely change the state of hydraulic connectivity.

The Russian River contributes sediment to the coast within the Russian River Littoral Cell, which is generally between the headland just north of the mouth and the Bodega Head headland, with net longshore sand transport toward the south (USGS, 2006, Griggs, Patsch and Savoy, et al, 2005; Patsch and Griggs, 2004; all referencing Habel and Armstrong,1978) (Figure 1). The estimated yield of sand and gravel to the shore is about 140,000 cubic meters per year, which is reduced about 17% from the natural supply rate due to the effects of upstream dams (Willis and Griggs, 2003). Watershed intervention also reduces peak flows during the winter and steadied summer low flows (PWA, 1993). Rates of shore change based on historic maps and aerial photographs show accretion in the vicinity of the Russian River mouth, and erosion just south of Goat Rock (USGS, 2006). These changes may be related to the construction of the early 20th-century construction of an elevated road (currently a parking lot) between the shoreline and the coastal headland Goat Rock that filled in a natural tombolo or sand spit. This road fill blocks the southward sand transport except for sand which bypasses around the seaward end of Goat Rock (Figure 2). The implication is that the beach at the Russian River mouth may be wider now than before the road to Goat Rock was built, and the effect of the jetty needs to be distinguished from the effects of other actions. It should be noted that the littoral cell has not been studied in detail, and refinements of the Habel and Armstrong (1978) cell descriptions have been made elsewhere. Behrens (2006) hypothesizes that longshore sand transport affects the river mouth morphology.

The inlet, the connection between the Estuary and ocean across the barrier beach, shifts between three states – tidal, closed, or outlet. When ***tidal***, the inlet allows the water level oscillations associated with the tides into the Estuary and allows the river inflow to drain out. The fresh river inflow and ocean seawater mix within the Estuary, creating fresher conditions during the wet season's high river flow and saline conditions during dry season's low river inflow. When the inlet becomes longer and/or constricted in cross section, muted tidal conditions can occur. Because muting limits saline ocean inflow, this state may promote fresher conditions in the Estuary that could improve salmonid habitat. When muted, the inlet is susceptible to closure by the combination of ocean waves and tides creating elevated water levels that deposit more sand in the inlet than flow through the inlet can remove. When the inlet is ***closed***, thereby forming a lagoon in the Estuary, river inflows cause the lagoon water surface elevations to rise. If the barrier beach is high enough, the water surface elevation may rise to the point of creating a flood risk to adjacent properties. To avoid flooding, the Water Agency breaches the beach with earth-moving equipment, returning to open tidal conditions. Observations in recent decades indicate that the Estuary is typically tidal, with an average of six closures per year (ESA, 2010). Closures typically last one or two weeks, and end with Water Agency breachings. In response to the Biological Opinion, the Water Agency now strives to create the third state, an ***outlet*** channel, between May 15th and October 15th. The outlet channel is intended to convey flow over the barrier beach, while minimizing tidal and wave-induced inflow of saline ocean water into the Estuary. By doing so, the outlet channel may create a deeper freshwater surface layer in the lagoon while minimizing flood risk. Under target conditions, the outlet channel and groundwater seepage through the beach may convey water to the ocean at a rate matching river inflow. This balance of inflow and outflow would sustain roughly constant water surface elevations in the lagoon.

For the purposes of this study plan, the Biological Opinion 's term 'jetty' is assumed to refer to the entire set of manmade structures that are north of the northernmost parking lot (parking lot) at the Goat Rock State Beach. As described below, all of these components of the jetty may affect lagoon water surface elevations. The parking lot and roadway to the south are not considered part of the jetty because they do not lie between the estuary and the ocean and are in active use by State Parks. In this document, the components of the jetty are referred to with the following terminology (Figure 3):

- ***Jetty, jetty complex, or complex*** – All manmade structures on the Goat Rock State Beach north of the parking lot that were constructed to stabilize the inlet at the mouth of the Russian River.
- ***Groin*** – The northern portion of the jetty, which is constructed of rocks, several feet in diameter or larger, and capped with concrete. At its south end, the groin starts aligned with the barrier beach, then bends to the northwest and angles obliquely into the ocean.

- ***Access elements*** – Extending between the southern end of the groin to the parking lot, the access elements collectively consist of the roadway, seawall, and railway, which were built to transport rock from the quarry at Goat Rock and other construction material to the groin
  - ***Roadway*** – The western most access element, consisting of compacted fill that supports an improved road surface.
  - ***Seawall*** – A timber fence, aligned between the roadway and railway, built to protect the railway from waves and encourage sand deposition.
  - ***Railway*** – The foundation, ballast, and railroad tracks just to the east of the seawall.

Some assessment tasks proposed below require access to the Goat Rock State Beach. Since this access may include areas closed to the public and involve equipment deployments, the Water Agency or its contractors need access permits from the California Department of Parks and Recreation. A harbor seal haulout is located at Goat Rock State Beach and permits under the Marine Mammal Protection Act may be required. Permits will need to balance study objectives against State Parks' concern about interfering with public use and NMFS's concern about marine mammal harassment. Other tasks that involve longer periods of access and/or more disruption, such as hammer strikes for seismic surveys, will probably require additional permitting with Parks and NMFS. If equipment is deployed and left unattended, the Water Agency and its contractors will also need to take steps to limit the potential for vandalism.

The methodology for assessing the jetty's effect on physical processes will incorporate a phased approach by which the assessment methods of each phase will be informed by the information learned in the previous phases. The analysis of physical processes will incorporate a combination of the assessment methodologies described in each of the following sections. Some assessment methodologies, especially those labeled as “Optional”, may not be pursued if it is determined that this approach is not necessary to complete the analysis.

2.1 Jetty Structure

Because much of the jetty is encased in the beach and documentation is minimal, the extent and composition of the much of the jetty's structure is uncertain. Therefore, a necessary first assessment is to describe the jetty's extent and composition in more detail. This description will inform subsequent assessments of the jetty's role in the physical processes which determine barrier beach formation and lagoon water surface elevations. An assessment of the geometry and material properties of the structures is also needed for engineering evaluations such as construction quantities and costs.

The jetty was intended to help maintain a navigable channel through the inlet. To move the large rock and other construction material over the soft beach sand to their final destination within the jetty required building infrastructure consisting of a roadway, seawall, and railway. These components, collectively referred to as the access elements, remain encased in the barrier beach. Only portions of the top of these access elements are visible, either where they protrude from the top of the beach crest or in cross section where the beach is incised.

While the history of the jetty construction is detailed elsewhere (PWA, 2010; Magoon, 2008), a few key points are summarized to highlight knowledge gaps of the current jetty conditions. Through several phases from 1929-1948, the jetty and accompanying seawall, roadway, and railroad were constructed, reinforced and then abandoned by various entities. There are few known records documenting the jetty design; the most useful is a single design drawing from 1938 that was revised in 1953. This drawing shows the structures' planform alignment and typical cross sections of the seawall and jetty (Figure 3). The scale, resolution, and quality of this drawing are marginal for inferring the jetty's role on physical process. For example, the drawing is not geo-referenced and it provides no information about the cross sections of the roadway and railway. In addition, the structures have deteriorated substantially since the drawing was made and maintenance ceased six decades ago.

2.1.1. Proposed assessment tasks – Jetty Structure

The purpose of the structural assessment is to develop a three-dimensional map of the extent of the jetty complex as well as estimate the composition of each portion of the jetty. The size and composition will strongly influence the magnitude of the physical processes which are the focus of subsequent assessments.

Several sources of information are available to conduct these tasks, including historical information, modern surface surveys, soil sampling, and geophysical study:

- Historic information includes design drawings, maps, photographs, reports. Information from local residents, libraries, and management agencies are also included as historical data. This information will provide an initial indication of the location, shape, size, and potentially, material used in construction of the structures. Geo-referencing scale drawings and aerial photographs and overlaying them on current aerial photographs would help refine new field sampling by detailing probable areas of the buried structures.

- A site assessment of present-day conditions would gather and map information readily available from parts of the jetty which are exposed at the surface. This information would include ground surface elevation (to indicate where jetty elements are present and where the jetty has been degraded) as well as the conditions of the structural elements that are visible (locations, shape, size, and, where possible, construction material). Ideally, the jetty should be surveyed when it is most exposed, which is probably late winter or early spring when the beach is at seasonal low elevation, and at low tide and calm wave conditions. This information would be recorded in a GIS database to facilitate mapping and comparison with other data.

- Soil sampling collected from the roadway and railway access elements would be analyzed for its geotechnical properties to better define the material which comprises these elements. These samples, collected either shallowly from exposed faces or at depth via excavation and/or coring, would provide information about the physical properties (grain size, material type, degree of compaction) of the elements.

- Geophysical assessments provide tools for remotely observing the subsurface portions of the jetty complex. Their general principle is to observe the way in which emitted waves (radio or acoustic) are reflected differently from subsurface materials. These tools can provide a three-dimensional map of the complex and may also provide indications about spatial change in composition, particularly if the geophysical methods are correlated with the soil sample results. Two recommended methods for this assessment are ground penetrating radar and seismic sensing (Hubbard, 2011). The ability of these two methods to resolve subsurface features depends on the nature of those features, so the best method or combination of methods may vary for the different components of the complex. The most appropriate method or combination of methods could be determined by a site visit and preliminary testing by geophysical experts. The seismic method could either be passive, relying on the ocean waves as a sound source, or use an active source such as hammer strikes. Probes can discern the bottom of sands and the surface of structures and help validate the geophysical measurements.

2.2 Groundwater Permeability

In the context of this plan, groundwater permeability[2] is the property of the barrier beach which determines the rate of groundwater flow through the beach. Groundwater flow results from water level differences between the Estuary and the ocean. Permeability is largely determined by the size, type, and arrangement of the particles within a porous medium. Groundwater permeability affects lagoon water surface elevations because permeability determines the seepage rate at which water from the lagoon exits to the ocean through the barrier beach. When the estuary is either closed or perched due to the establishment of an outlet channel, it is estimated that one of the major sources of outflow from the lagoon is seepage flows through the barrier beach (Largier and Behrens, 2010).

Because the jetty complex is comprised of various soil types and rock sizes and it was constructed as a permanent structure, the materials comprising the complex probably have different permeability than natural beach sands. However, the sign, magnitude, and spatial variation of the complex's permeability relative to beach sand are not known. Therefore, the net effect of the jetty, whether it results in an overall increase or decrease in seepage through the jetty-influenced beach as compared to a natural beach, is not known.

Using a water balance approach to analyze closure periods, Largier and Behrens (2010) estimate the total seepage rates from the lagoon to range between 30-80 cubic feet per second (ft^3/s) and to average 60 ft^3/s. Their estimates suggest that seepage rates increase by approximately 20 ft^3/s per foot of head difference. Although this analysis demonstrates a direct relationship between water surface elevation difference and seepage, there is substantial, unexplained scatter in the relationship, e.g. ±20 ft^3/s for a specific water level difference. Most of the seepage is thought to occur in through the upper

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[2] Permeability is a general term that is independent of the type of fluid passing through the porous medium. When dealing exclusively with water, the related proportionality constant 'hydraulic conductivity' is often used. We maintain the term 'permeability' for consistency with the BO.

portion of the barrier beach where the jetty complex resides, but could also be directed laterally into the estuary's freshwater aquifer. Seepage rates within the beach probably decrease with depth as the barrier beach becomes wider. Largier and Behrens (2010) note an increase in seepage rate for lagoon water surface elevations above 3-4 ft NGVD and speculate that this may be the result of vertical changes in permeability resulting from the jetty complex. Modeling of the salt field also suggests that most seepage occurs in the upper portion of the estuary (Largier and Behrens, 2010).

The jetty's permeability is likely to vary between its different components (jetty, roadway, seawall, and railway) since they are made of different materials, with different methods, and are in varying states of degradation. Besides differences in permeability, the components have different sizes and orientations to the direction of seepage. Relative to a natural barrier beach, some portions of the jetty, such as the large rocks in the groin, may increase the permeability. Other portions of the jetty, such as the compacted roadway and railway fill, may reduce the permeability. In addition, by affecting the setting and duration of beach sand deposition, the jetty may alter the permeability of the beach sands deposited about its flanks. For instance, the beach containing the jetty is wider than the beach to the north that hosts the outlet channel. The complex may have also altered the grain size and compaction of the sand around it. The complex's integrated effect on lagoon water surface elevations depends on the magnitude of local permeability and the spatial extent of these variations. Determining these parameters is the focus of the proposed assessments.

Besides reducing lagoon water surface elevations directly, permeability interacts with inlet and beach morphology, jetty-influenced processes discussed below. For instance, permeability affects inlet morphology since water exiting the lagoon as seepage reduces the amount of water that needs to be conveyed by the outlet channel to maintain constant lagoon water levels. If the outlet channel does not need to convey as much flow, it would be less susceptible to scour that can convert the outlet channel to a tidal channel. Permeability can also affect inlet morphology because more seepage results in slower rise of lagoon water surface elevations after closure, potentially resulting in longer closures and reduced flood risk. Anecdotal evidence from the 19th century (Behrens et al., 2011) and severe drought conditions (1977 and 2009), provide examples when the Russian River lagoon stayed closed for long periods because, in part, seepage may have comprised a larger fraction of outflow to the ocean. Removing the jetty would also afford the inlet and the ocean waves a larger role in beach morphology. Beach morphology, which is discussed in more detail in Section 2.4, may affect permeability via beach width and possibly the sand deposition conditions.

2.2.1. Proposed assessment tasks - Permeability

The jetty structure assessment, described previously, is a valuable pre-cursor to these permeability assessments because it maps the extent of the jetty complex's components. Investigating the permeability of the barrier beach can be accomplished by a combination of direct and indirect methods.

- Grain size analysis of subsurface soil samples from the beach, roadway, and railway may provide an indication of relative permeability between these soil sources. The permeability of the samples can also be tested in the lab with a permeameter, but the disturbed sample may not provide an accurate representation of in situ permeability.

- Groundwater monitoring wells (or piezometers) can be used to monitor groundwater surface elevations in the barrier beach. Groundwater level data can be analyzed and interpreted to make inferences about seepage flows through the barrier beach. Typical well installations are 5-15 ft sections of pipe inserted into the beach which then have instruments deployed inside. For long-term deployments, it may be possible to bury the well below existing grade so it is covered by sand to reduce its impact on the beach and limit vandalism.

- To infer properties of permeability and flow rate from well water level observations, the temporal response of water level to a change in forcing must be monitored. This change in forcing can be imposed, such as a slug or bail test, which adds or removes water to the well, respectively. A shallow version of an added-water test is an infiltrometer. Another changing in forcing would be a closure and subsequent increase in lagoon water surface elevations.

- Water quality monitoring expands observations in the monitoring wells to include temperature and conductivity, and provides additional information about seepage rates. Temperature and conductivity can serve as tracers and, in combination with SCWA's observations of these constituents in the estuary, provide estimates of travel times between the estuary and within the barrier beach. Temperature and conductivity can serve as ambient tracers during a lagoon closure event when the water surface elevations rise in the lagoon and an upper freshwater layer develops (Behrens and Largier, 2010). These measurements can also inform understanding of salt water surface elevations and infiltration to the estuary. When the infrequent and unpredictable lagoon closures are impractical with monitoring mobilization demand or for targeted studies, injected tracer studies may be used. Injected tracers can include natural constituents such as fresh water and salt water, or harmless dyes. Tracer observations at different depths can reveal the vertical structure of seepage.

- Ground electrical conductivity – Because the presence of moisture alters the electrical conductance of soils, relative changes in electrical conductivity can be used to detect location of faster seepage across the jetty complex. Different instrumentation can be used to measure conductivity, including cabled electrodes placed in the beach, hand-held electromagnetic meters, or cable loops for electromagnetic induction. These tools help map zones of relative seepage rates, in which the rates must be quantified with well-based tests described above. Like the well monitoring, more information can be determined from temporal variations in these measurements in response to lagoon water surface elevation changes. Initial screening by some methods may indicate the utility of other follow-on methods. Methods which may be used for this study include:
  - Identifying high seepage zones that might exist due to the jetty
  - Mapping spatial distribution of seepage rates throughout the beach
  - Comparing relative seepage rates between (1) the barrier beach that lies south of the groin and has the embedded jetty elements and (2) the barrier beach north of the groin where the inlet occurs (Figure 3)

  - Estimating effective permeability constants

- (Optional) Groundwater model – Depending on the findings of the data collection subtasks listed above, a numerical model to predict the spatially and temporally varying seepage rates may be recommended to integrate the observed existing conditions. Besides validating estimates of permeability inferred from the observations, a numerical model could be used to evaluate alternatives by testing system response to proposed jetty modifications.

- Refined water balance model — Observations of groundwater and water surface elevations can be combined with other coincident information such as riverine flow rates, ocean levels and atmospheric conditions to refine the prior water balance budget modeling used to estimate seepage rates (ESA PWA, 2011; Largier and Behrens, 2010). Whether the data will be sufficient to calibrate or simply improve and verify the model as a tool is not known.

2.3 Inlet Morphology

Inlet morphology refers to the changes in inlet dimensions and alignment that occur in response to river discharge, tidal exchange, and ocean waves and cause the formation of a barrier beach. Inlets are very dynamic systems that can rapidly change state at the tidal time scale of hours or be quasi-stable for months. Because its shape determines the magnitude and direction of the flow between the estuary and the ocean, the morphology of the inlet is a key determinant of the estuary water surface elevation. The inlet is characterized by dynamic morphologic change in response to changing conditions. To the extent that the jetty affects these dynamic changes, it could also affect inlet functions such as alongshore sediment transport, which, in turn, can affect groundwater seepage, wave overtopping and breaching characteristics. Hence, interventions such as the jetty can impair some functions, and then require a succession of interventions to mitigate functional degradation. Therefore, removal of the jetty could be beneficial not just to inlet morphology, but also to its related functions, such as sediment transport and ecosystem renewal.

To achieve the Biological Opinion target conditions of a freshwater lagoon perched above tides and below flood stage requires the inlet morphology to be changed from its most common state as a tidal inlet to either a closed or an outlet channel state. For the anticipated river inflows and existing seepage rates, a closed channel would typically lead to lagoon water surface elevations rising beyond flood stage, thereby necessitating management to create an outlet channel. Therefore, this assessment focuses on the jetty's possible effects on the frequency and duration that an outlet channel can be established. The jetty may also affect the frequency and duration of muted tidal conditions. Even though a muted tidal state does not achieve the Biological Opinion targets, it may provide some benefit to salmonid habitat by increasing the depth of the freshwater surface layer. The jetty's potential effects on muted tidal conditions will be assessed, but may be difficult to discern since these conditions are often transitional, and are less distinct from other states.

The jetty may have a direct effect on estuary water surface elevations if it changes the frequency at which the inlet changes between the three morphologic states (tidal/closed/outlet). Whether or not the jetty's effect is favorable to the target estuary water surface elevation depends on which state changes the jetty affects. Transitioning out of tidal inlet conditions is a prerequisite to achieve target water surface elevations and therefore is favorable, particularly if it occurs sooner in the management period. In some instances, this transition may include a period of partial closure and muted tides. The jetty may shorten or prevent these muted tidal periods, perhaps by forcing a southward migrating channel to close. Most likely, tidal conditions will change to closed rather than an outlet channel. Conversely, breaching of closed or outlet state to tidal returns tides and salt to the estuary and is least favorable from the perspective of Biological Opinion habitat management objectives. A state change from closed to outlet channel is favorable, but probably requires management action and at present does not involve the jetty. Closing an outlet channel is likely to cause flooding if an outlet channel is not re-established by management action.

Because the changes to inlet state are threshold events within a dynamic system, efforts to create predictive models have taken the form of quantifying geomorphic relationships with empirical data. For example, the state change from tidal to closed has been examined in some detail for the Russian River (PWA, 1993; Behrens et al., in prep). In addition to the tidal-closed shift, Battalio et al. (2007) also quantified the change from closed to tidal.

There are several ways in which the jetty may alter estuary water surface elevations by altering state changes between inlet morphologies. As noted above, whether or not these state changes are favorable to achieving target estuary water surface elevations is a function of the specific pair of before/after states. The potentially significant linkages between the jetty, inlet morphology, and estuary water surface elevation include:

- The jetty restricts the southern migration of the inlet. As shown in Behrens et al. (2009), during the management season the inlet typically oscillates between the jetty and 100 m to the north. When the inlet develops along an alignment exiting the estuary north of the jetty and angling south across the barrier beach, the jetty may cause the inlet mouth to pinch off and close rather than continue migrating further south. Promoting tidal inlet closure would be favorable; promoting outlet channel closure would be unfavorable (but manageable).
- If the inlet is located parallel to and just north of the jetty and not being forced south against the jetty to the point of closure, the jetty may help the inlet resist closure. This was the original purpose of the jetty (Magoon et al., 2008) and historic wave analysis indicates that the jetty is located near the minimum wave energy for a range of wave conditions (Johnson, 1959). Preventing tidal channel closure would be unfavorable; preventing outlet channel closure would be favorable.

In addition to these direct linkages between the jetty, inlet morphology, and estuary water surface elevation, the jetty may affect other aspects of the system, which then alter water surface elevations. These linkages are noted here and discussed in the other relevant sections on physical process:

- The potential for the outlet channel to scour and convert to a tidal inlet is a function of the flow rate it must convey. The outlet channel's flow rate is dependent on seepage flows through the barrier beach, which may be influenced by the jetty if it alters the barrier beach's permeability (Section 2.2).

- The inlet is a feature incised in the barrier beach, and so depends, to some degree, on the jetty's effects on the overall beach morphology. For example, if the jetty alters the width of the beach, this may affect the bed steepness in the outlet channel, which in turn, may influence the channel's sediment transport capacity.

The inlet morphology is related to beach morphology in Section 2.4 below.

2.3.1. Proposed assessment tasks – Inlet Morphology

Assessing the potential inlet morphology requires a broad suite of information, including topographic characterization of the beach, studies on the local wave climate, and wave modeling over the full extent of the geographic region. Wave-driven sediment transport is the constructive process that results in the beach barrier at the Russian River Estuary's inlet. Hence, wave driven processes are key to beach and inlet morphology. Once wave conditions are characterized, the potential effects of the jetty structure can be evaluated, and provide an assessment of the implications of removing the existing jetty. The nearshore wave climate is also pertinent to diagnosing the effect of filling the Goat Rock tombolo on beach widths and coastal flood risk. Therefore, while the wave modeling is described herein as part of the inlet morphology analysis, the wave analysis is a fundamental component of understanding the jetty and supports other parts of the analysis.

- Researchers at the Bodega Marine Lab have developed a multi-year record of inlet state, including its location, width, and likelihood of closure. This record can be interrogated, along with tidal, river discharge and wave conditions, to characterize the effect that the jetty may have on inlet morphology. Both statistical and case studies of particular events can be used to develop and refine conceptual models of inlet behavior, relating forcing parameters (water surface elevations, wave conditions, river conditions) to the shapes and dynamic responses of the mouth.

- The sensitivity of wave overwash volumes due to barrier beach geometry can be estimated from coastal engineering methods (e.g. the Corps' CEM) to predict if the jetty influences wave overtopping as a mechanism for breaching.

- Update wave refraction and diffraction analysis along Goat Rock State Beach. The analysis would aim to characterize the location and extent of local wave energy minima and sediment transport gradients under different wave conditions. These gradients are thought to influence inlet morphology. Wave transformation coefficients would be developed in the analysis, and can then be used to transform offshore wave data (available from wave buoys) to nearshore wave conditions. The transformations can be validated by observing nearshore conditions, most likely by visual observation or video camera, or ideally by a nearshore wave gauge if funding is available[3].

3 Nearshore wave collection for several months would likely cost about $40,000, and there may be cost sharing opportunities with other programs such as the Coastal Data Information Program.

- (Optional) Depending on the findings from the wave refraction and diffraction analysis, a two-dimensional wave model such as SWAN may be employed to provide additional spatial resolution. This second step in the wave analysis produces multiple, more refined wave transformation functions for multiple locations along the shore. Essentially, the wave model is applied within a smaller zone from about the 40 ft depth to shore, with a much higher grid resolution. Nearshore bathymetry can then be modified to represent different beach conditions, and the currents such as a discharge from the river can be added. The variability of along shore transport can then be investigated, and wave data for wave runup calculations can be generated. By removing the groin from the model, the magnitude and spatial extent to which the groin alters the wave energy can be evaluated.

2.4 Beach Morphology

As the barrier that creates the lagoon and hosts the inlet, the beach is a dynamic feature whose morphology and formation exerts control over the water surface elevations inside the lagoon. Two key components define the beach morphology: sediment supply and coastal processes. The beach morphology is closely related to the inlet morphology addressed in Section 2.3 above.

Goat Rock State Beach is a pocket beach set among the cliffs and bluffs abutting the ocean north and south of the river mouth. As such, the beach is geographically disconnected from regional alongshore sediment transport. This disconnect is evident in the opposing directions of net alongshore transport: the trend appears to be northward on Goat Rock State Beach, but is southward for the regional coastline (Johnson, 1959). Goat Rock State Beach was further disconnected from alongshore sediment transport by early 20th-century construction of an elevated road between the shoreline and the coastal headland Goat Rock, filling in a natural tombolo or sand spit. Historic data indicate accretion at the river mouth and erosion south of Goat Rock (USGS, 2006).

The riverine sediment supply has been heavily affected by land use and water management practices in the watershed (PWA, 1995). For example, sediment loads are thought to have increased due to logging in the watershed and decreased due to gravel mining and dam construction. Recent analysis of sediment yields in the lower estuary suggests sediment yields on the order of 100,000 tons/yr (PWA, 1992). A comparison of bathymetry surveys from 1992 and 2009 indicates that the lower river and estuary have not exhibited significant bathymetric change, suggesting the estuary is at or near equilibrium with respect to its sediment budget.

For coastal processes, the beach experiences seasonal variation in width and height in response to changes in wave conditions. This process – beach to bar exchange – results from winter storm waves that erode beach sediment and deposit it as offshore bars followed by low steepness swell in the summer that promotes onshore delivery of sediment and creation of a barrier beach.

Past management practices on the beach and in the watershed have probably altered the width and elevation of the barrier beach. An understanding of past beach evolution and current trends can be developed with geo-referenced, aerial photographs and maps to provide landform data characterizing both historic and current trends. This analysis is probably also necessary to answer questions that will likely arise during the permitting process with the Coastal Commission.

Since the groin was never completed to its design length and has since deteriorated, its present form probably does not block alongshore sand transport to the extent originally intended. The access elements embedded in the barrier beach have also deteriorated such that they currently form an irregular barrier to wave overwash. In some locations where it is higher and protrudes from the beach, the jetty blocks overwash. Where the jetty doesn't protrude from the beach, wave overwash flows are less impeded over the beach and into the estuary, delivering sand further landward than in areas blocked by the jetty. Overwash is a key process in setting beach morphology. If the jetty is disrupting overwash, it may also be disrupting the barrier beach morphology.

In response to predicted increases in mean sea level, the beach is expected to transgress (move up and landward) (PWA, 2009). As the rate of sea level rise increases, the landward transgression rate will similarly increase. This process may be augmented by climate-change increases in winter storm frequency and intensity. Since the jetty is fixed in place, it could impede this landward migration even as the landward shift in wave energy would likely expose more of the jetty.

2.4.1. Proposed assessment tasks – Beach Morphology

The assessments of beach overwash and wave modeling proposed above for inlet morphology (Section 2.3.1) can be incorporated into and expanded upon when assessing beach morphology. The wave modeling would be expanded by using the predicted wave field as input to a nearshore and beach morphologic model.

- Geo-reference, analyze and compare historic maps, data, and photos to describe the evolution of the beach width, shoreline location, and topography. The assessment will need to consider seasonal variations and historic riverine sediment yield (see related task below) to place beach changes in context. This analysis can proceed on several scales, from the entire nearshore to beach profiles where the jetty blocks overwash as compared to adjacent profiles where it does not block overwash. An initial list of sources includes: 1879 T-Sheet, USCGS survey from 1930-1, Corps surveys from 1960s, aerial photographs (PWA, 1993; Table 3.3), LiDAR, and recent Water Agency surveys.

- Conduct a review of historic and current sediment budgets for the beach and its adjacent compartments to understand the volume and type of sediment supply and deficits affecting the beach.

- Analyze beaches fronting other bar-built estuaries as reference sites to bracket the range of beach width and height.

- Survey beach geometry, including beach elevation. Coincident with the survey, measure wave runup elevation. Compare with transformed waves and calculated runup to verify wave modeling and wave transformation analysis (see Section 2.3 for wave transformation analysis).

- (Optional) Morphologic modeling with a two-dimensional tool such as XBeach can predict the behavior of the beach and, by extension, the effects on lagoon water surface elevations. XBeach is the newest version of shore profile response models which attempt to quantify the shore response to a change in water level and wave conditions. For example, the model predicts the extent of erosion and profile change that results from a winter storm characterized by elevated water levels and incident waves. The sediment budget and wave modeling from prior subtasks would be used as boundary conditions for this model. The assessment of historic beach evolution would provide geomorphic context for verifying model results. Changes to beach morphology that may result from jetty alternatives could also be evaluated with the model.

2.5 Flood Risk

In contrast to the previous topics, flood risk is not a process which affects lagoon water surface elevations or barrier beach formation. Instead, flood risk is affected by the jetty and the jetty's effect on lagoon water surface elevation and beach morphology. An assessment of flood risk is included in this study because it is a potential significant impact of jetty modification. Jetty modification designs would strive to not increase the existing level of flood risk. However, if jetty modifications "appreciably increase flood risk" (Biological Opinion, p. 251), they may not be implemented. The effect on wave propagation and coastal flood risk is pertinent to environmental review under CEQA.

FEMA's existing flood assessment for the Estuary maps the 100-year fluvial flood levels to within 1,500 feet of the barrier beach. At this location and upstream, the 100-year water surface elevations are set by fluvial discharge. The 100-year water surface elevations start at 12.5 NGVD, approximately 6 feet higher than the 100-year tidal still water level. If jetty modifications cause changes to beach morphology, this could affect the way in which coastal floods propagate into the lagoon.

During the lagoon management period (May 15 – October 15), flooding is not driven by extreme river flow and/or storm surge events; these events typically occur as the result of winter storms. Instead, increases in lagoon water surface elevations occur after ocean waves cause the natural closure of the Estuary's inlet. Once the inlet closes, inflows into the lagoon (fluvial discharge, reservoir releases and wave overtopping), exceed outflows, causing the water surface elevation to rise. Elevated lagoon water surface elevations resulting from inlet closures are the most likely cause of flood inundation during the management period. Once lagoon water surface elevations exceed 9 ft NGVD, structures on adjacent properties can be impacted. During the management period, the Water Agency currently manages water surface elevations in efforts to prevent flooding through the excavation of an outlet channel. In situations of imminent flooding, breaching the barrier beach to establish tidal inlet conditions may be practiced. Waves inside the lagoon, which either come from ocean waves overtopping the beach or local wind generation, may further exacerbate flood risk. Jetty modifications may affect these conditions by changing the frequency and duration of elevated lagoon water surface elevations or by altering the beach morphology, and therefore, the propagation of ocean waves into the lagoon.

2.5.1. Proposed assessment tasks – Flood Risk

Changes to flood risk may occur in response to jetty changes to the beach morphology and the frequency and duration of lagoon water surface elevations. The wave study discussed in Sections 2.3 and 2.4 above for the inlet and beach morphologies will assist in characterizing the incoming wave field, which can then be evaluated for the potential for overtopping and/or propagation into the lagoon. Proposed flood risk assessments include:

- Develop a preliminary coastal flooding assessment for the Goat Rock State Beach generally consistent with FEMA's Guidelines for Pacific Coast Flood Studies (FEMA 2005) and similar to that accomplished State-wide by PWA (2009). This assessment builds upon the coastal assessments in Sections 2.3 and 2.4. The wave transformation and runup calculations will be extended to extreme (less frequent) conditions that are close to the 100-year event. This assessment will indicate the key parameters which contribute to the total water surface elevations that can inundate the Estuary shoreline. Forcing parameters which contribute to the ocean's total water level include the still water level, storm surge, waves, and wind setup. These forcing parameters can drive water surface elevations over the barrier beach, whose morphology may be altered if the jetty is modified. A range of scenarios should be evaluated with the model, including:
    - Extreme coastal flood events associated with winter storms
    - Target lagoon subject to closure and then multi-day wave events that prevent Agency equipment from safely accessing the beach for breaching
    - Identify combinations of barrier beach elevations and lagoon water surface elevations which may result in ocean wave propagating into the lagoon and increasing flood risk.

- (Optional) Extreme water surface elevations in the Estuary are a combination of coastal flood conditions and fluvial discharge. An analysis of the probability of joint occurrence of coastal flood conditions and fluvial discharge would provide a refined estimate of the total water surface elevations in the Estuary. This analysis is often accomplished with coincident time series (ideally observed, but often estimated) so that the probability of the response (estuary water surface elevations) is less dependent on assumptions of joint probability (Garrity et al, 2007).

3. Jetty Alternatives Feasibility

If one or more the jetty effects assessments indicate that the jetty is an impediment to the management of lagoon water surface elevations to meet the targets of the Biological Opinion, then the Water Agency will develop and evaluate alternatives to the jetty. This section describes the approach for studying the feasibility of jetty alternatives.

Development of alternatives and evaluation of their feasibility will rely on information and understanding derived from the effects assessments (Section 2). To be implemented, an alternative will need to address multiple objectives, some of which may be in conflict. To make the objectives explicit, the feasibility study's first two steps consist of identifying opportunities and constraints as well as performance criteria. The next step will be to develop alternatives and define them in sufficient detail that their feasibility can be evaluated. The evaluation step will then employ many of the tools developed in the effects assessments, with appropriate modifications to represent the alternatives. The results of this feasibility assessment will inform the decision as to whether or not modifying the jetty is warranted to encourage the lagoon water surface elevations and a closed barrier beach targeted in the RPA. If jetty modification is pursued, these assessments will also inform permitting for the modification action.

3.1 Opportunities and Constraints

Jetty alternatives require balancing multiple objectives, such as ecologic goals, infrastructure protection, and cost. Early identification of a site's constraints is essential to achieving these objectives, making the most of site opportunities, and avoiding project delay. Alternatives should aim to capitalize on opportunities for desired outcomes, and reduce constraints that otherwise would limit these outcomes. Below are some examples of opportunities and constraints that likely to apply to the jetty. The study will revise and add to these lists as indicated.

3.1.1. Opportunities

- Altering the jetty may increase seepage through the barrier beach, reducing the discharge that the outlet channel must convey in order to maintain lagoon water surface elevations.
- Removing the jetty may affect sand transport patterns and associated beach and inlet morphology, thereby affecting breaching and estuary water surface elevations.
- Restoring natural beach processes could allow more resilience to anticipated sea level rise impacts, including higher water surface elevations and increased erosion.

3.1.2. Constraints

- Native plants, particularly the federally endangered Tidestrom's lupine, grow on portions of the jetty

- Marine mammals use the beach for haulout and pupping, which may limit access for planning and construction
- The beach is a well-used recreational area; alternatives should preserve public safety and minimize impacts to public access.
- Permits from several oversight agencies are required to manage the beach, including State Parks, the Coastal Commission, the State Lands Commission, and the U.S. Army Corps of Engineers.
- Wise allocation of financial resources will be needed to secure and apply funding for this project.

3.2 Performance Criteria

Performance criteria provide transparent and quantitative metrics for evaluating the proposed alternatives. Performance criteria include not only the technical objectives of the project such as hydraulic, geomorphic, and structural elements of the design, but also the broader context of habitat and socio-economic constraints. The criteria can be thought of as quantification of objectives. For example, “no increase in flood risk” might be translated to a criterion of maximum water elevation. These criteria would be developed iteratively through documented discussion between the Water Agency and its consultants, resources agencies, and stakeholders. Based on the effects assessments, project opportunities, and constraints, performance criteria will be proposed to guide alternatives development and evaluation.

3.3 Alternatives Development

The Biological Opinion proposes several alternatives for removing or modifying the jetty to help achieve target lagoon water surface elevations. Once the effects assessments described in Section 2 are completed, additional alternatives may also be proposed. The alternatives then require clear definitions for use in planning, permitting, and evaluation. These definitions will be tailored to increase each alternative’s performance relative to target lagoon water surface elevations and other design criteria. As evaluation of the alternatives progresses (Section 3.4), they would be iteratively refined. The brief descriptions below provide an initial list of alternatives which may be considered in the feasibility study.

3.3.1. No modification

Consideration of not modifying the jetty establishes a baseline against which to compare the modification alternatives. No action is likely to be defined according to the current practice of not maintaining the jetty unless it was an immediate threat to public safety.

3.3.2. Complete removal

Complete removal of the jetty entails deconstruction and removal of all components of the groin, roadway, seawall, and railway. Depending on the volume of material removed, fill may be used to supplement the natural beach sand. The beach would be re-graded to create a more naturally occurring beach profile.

3.3.3. Partial removal

Partial removal of the jetty entails deconstruction and removal of some components while leaving other components in place on the beach. A limited approach may be more feasible if certain jetty components are thought to have a more significant effect on lagoon water surface elevations. Options for partial removal might include:

- Notch for outlet channel entails an engineered opening to provide grade control for the the outlet channel.
- Removal of groin entails removal of the large rock and concrete structure extending into the nearshore zone.
- Removal of access elements entails removal of either sections or all of the roadway, seawall, and railway on or in the beach.

3.3.4. Subsurface flow enhancement

Subsurface flow enhancement entails an engineering solution, such as installation of subsurface gravel beds, which enhance seepage of through the beach.

3.4 Alternatives Evaluation

To address the project goal (achieving target lagoon water surface elevations), the alternatives will require evaluations with respect to the physical processes that contribute to lagoon water surface elevations. These physical processes, whose linkages to lagoon water surface elevations will be studied according to the assessments described in Section 2, include permeability, inlet morphology, and beach morphology. In addition, the alternatives' potential impact on flood risk will be predicted. Evaluations should consider both the short- and long-term response to the different alternatives. Long-term response should include anticipated changes caused by mean sea level rise.

Table 1 provides a template for the steps involved in evaluating the alternatives. For each alternative, its relationship to the key physical processes is described. This relationship then serves as the basis for the anticipated effect on the physical processes and water surface elevations. The analytic tools and models developed for the effects assessments will be used to evaluate the alternatives. Note that this table is only for illustration; the effects assessments will provide additional understanding as to the linkages between the physical processes and the lagoon water surface elevations.

In addition to the evaluation of these key linkages between physical processes and lagoon water surface elevations, the alternatives also requires consideration of public access, infrastructure, regulatory requirements, construction feasibility, and cost. These dimensions will be used to screen alternatives for any impacts which may preclude an alternative outright, negating the need for further analysis. As planning progresses, assessments of these dimensions will be conducted to a corresponding level of detail.

The dynamic environment of the beach creates a degree of uncertainty unlikely to be eliminated by comprehensive studies. The alternatives and physical processes will need to be assessed using the best available knowledge but the jetty plan will still require adaptive management and fallback planning.

Table 1. Alternatives Evaluation Template

			Physical Processes			
			Permeability	Inlet Morphology	Beach Morphology	Flood Risk
Alternatives	Complete Removal	*Relationship*	Structures may impede or slow the conveyance of water through barrier beach	Structures may confine the inlet characteristics of size, location, alignment	Structures may affect the littoral cell transport and negatively impact the natural beach morphology	Structures may encourage high lagoon water surface elevations by preventing breaches
		Anticipated Alternative Effect	Reconnection of subsurface pathways	Allowance of natural migration of outlet channel along beach, simplification of inlet management	Re-establish nearshore sediment transport pathways, allowance of natural beach morphology	Allowance for more consistent lagoon water surface elevations
		Assessment Needs	Modeling of subsurface flow, stability of barrier beach	Predictions of inlet characteristics	Modeling change in wave patterns, beach morphology patterns	Predictions of lagoon water surface elevations and breaching (either natural or mechanical)
	Partial Removal – Outlet Channel Notch	*Relationship*	none	Channel failure by scour or closure from natural processes forces human intervention to maintain channel integrity	Potential impedance to local beach morphology cycles near fixed channel	Channel would be fixed in place to maintain connection from lagoon to ocean
		Anticipated Alternative Effect	n/a	Allowance for management of the channel	Natural beach morphology cycles would be restored for most of the beach except for immediately around the fixed channel	Allowance for consistent management of the lagoon water surface elevations and reduce flood risks
		Assessment Needs	n/a	See "Complete Removal"	See "Complete Removal"	See "Complete Removal"

Table 1. (con't) Alternatives Evaluation Template

			Physical Processes			
			Permeability	Inlet Morphology	Beach Morphology	Flood Risk
Alternatives	Partial Removal – Groin Structure	*Relationship*	none	Structure may confine the inlet alignment and location by affecting the nearshore circulation patterns	Structure may affect the littoral cell sediment transport and negatively impact the natural morphology	none
		Anticipated Alternative Effect	n/a	Re-establish natural nearshore circulation patterns	Re-establish nearshore sediment transport pathways, allowance of natural beach morphology	n/a
		Assessment Needs	n/a	See "Complete Removal"	See "Complete Removal"	n/a
	Partial Removal – Access Elements	*Relationship*	Structures may impede or slow the conveyance of water through barrier beach	none	Structures may affect natural beach morphology	Structures may encourage high lagoon water surface elevations by preventing breaches
		Anticipated Alternative Effect	Reconnection of subsurface pathways	n/a	Re-establish natural morphology cycles	Allowance for more consistent lagoon water surface elevations
		Assessment Needs	See "Complete Removal"	n/a	See "Complete Removal"	See "Complete Removal"
	Subsurface Flow Enhancement	*Relationship*	Permeability of sand would be increased to encourage higher rates of transfer through beach from lagoon	none	none	Higher rates of transfer through beach would provide additional lagoon water surface elevation control
		Anticipated Alternative Effect	Reconnection of subsurface pathways	n/a	n/a	Allowance for more consistent lagoon water surface elevations
		Assessment Needs	See "Complete Removal"	n/a	n/a	See "Complete Removal"

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5. Figures

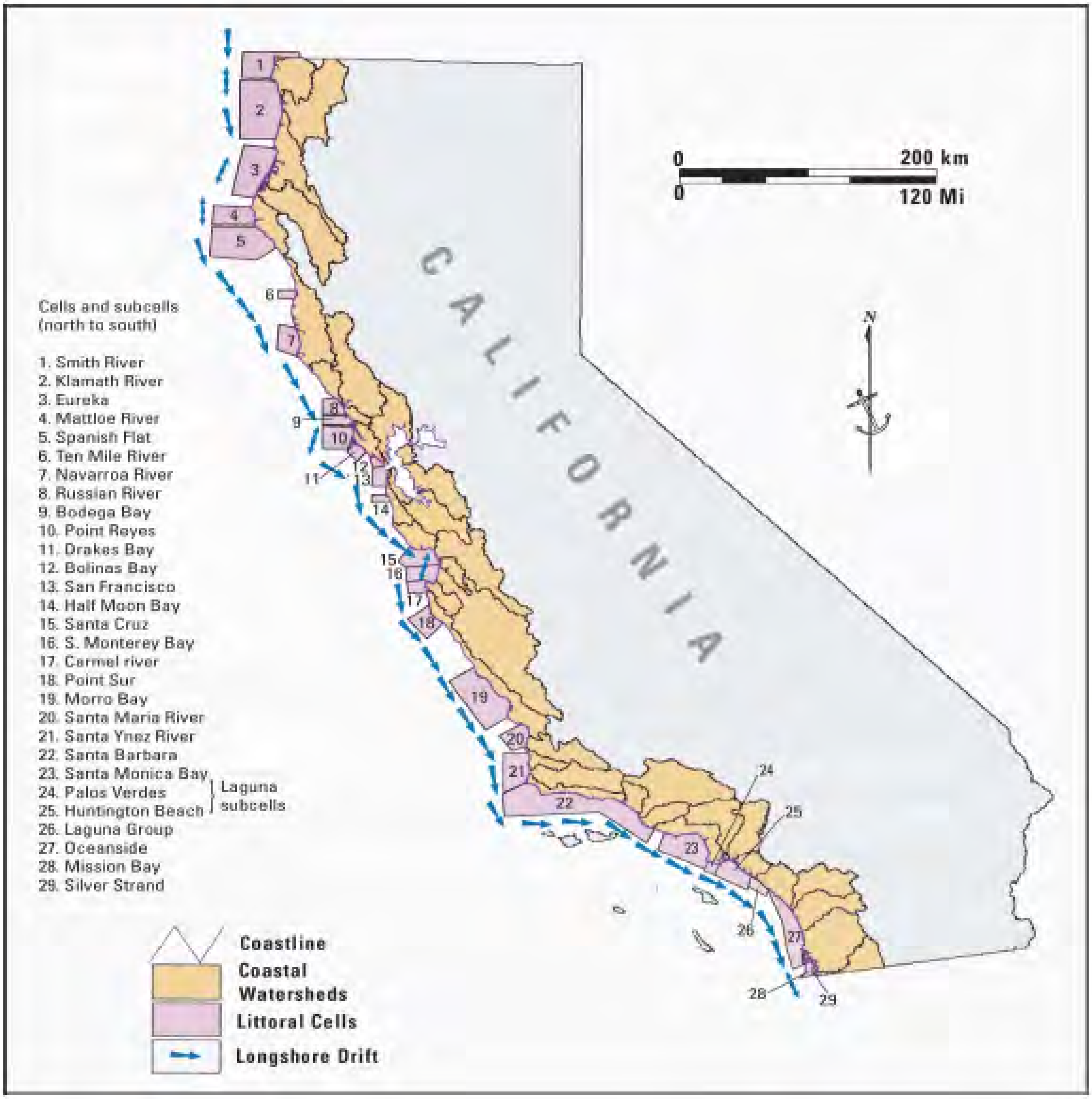

Figure 1. Littoral cells in California, from USGS (2006), derived from Habel and Armstrong (1978) Griggs, Patsch and Savoy, et al, 2005; and others. The Russian River Littoral Cell (number 8) is generally from just north of the mouth southward to Bodega Head.

Figure 2. Aerial oblique view of the Russian River mouth and Goat Rock (rock headland to right), looking east such that north is on the left side of the image (Source, Behrens, 2008). Note the narrow beach to the south of Goat Rock, and the wider beach to the north.

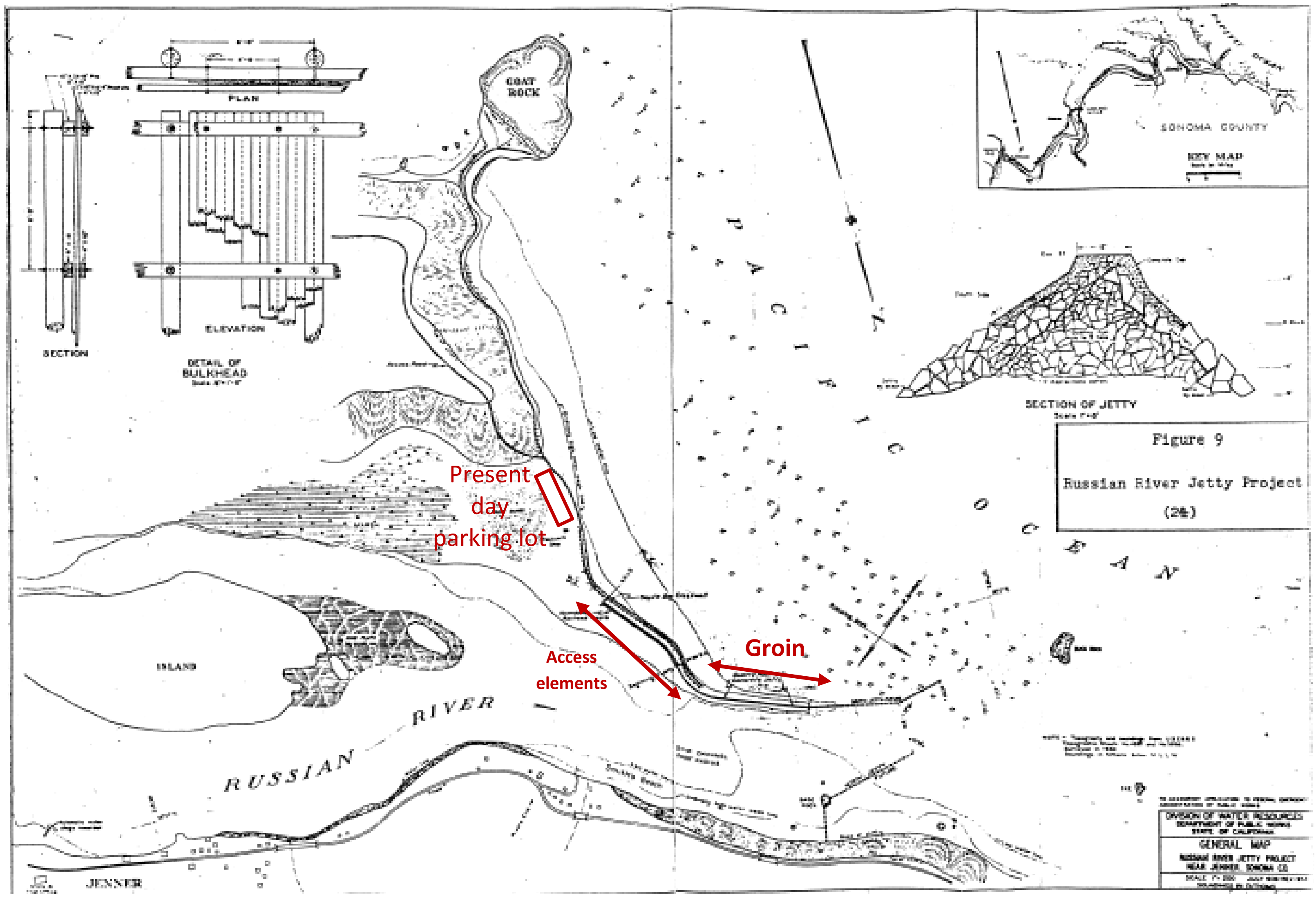

Figure 3. Drawing of Jenner Jetty – Groin, Roadway, Seawall, and Railway