A Tidal Hydrology Assessment for Reconnecting Spring Branch Creek to Suisun Marsh, Solano County, CA: Predicting the Impact to the Federally Listed Plant Soft Bird's Beak

Jessica J. Olson
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ABSTRACT

Spring Branch Creek drains a 2,670-acre watershed into tidally influenced Suisun Marsh in Suisun City, Solano County, CA. A farm levee road and berm that were constructed in the 1930s to drain the site for agriculture created an abrupt transition between fluvial and tidal systems. In the 1990s, the landowner Solano Land Trust installed two four-foot culverts beneath the levee road in attempt to partially restore the exchange of brackish tidal water with fresh water. Ten years later (in 2000), a population of federally listed plant soft bird's beak (*Chloropyron molle* ssp. *molle*, syn., *Cordylanthus mollis* ssp. *mollis*) was reintroduced in the high marsh zone under these altered hydrological conditions and is now a thriving population of 100,000 individuals. Now, a proposal to remove the levee completely, and reconnect fluvial and tidal systems, raised concern that the livelihood of this population might be compromised by altering the hydrological conditions.

I conducted a tidal inundation analysis to describe the differences in current inundation frequency, duration, and depth in the high and low marsh zones, and above and below the Spring Branch Creek culverts. I also created a water surface model to predict how these hydrological differences will change following reconnection. Results show that hydrological conditions in the high marsh zone, where soft bird's beak occurs, will not significantly change following reconnection, with tidal changes of only 5-6 cm. Water elevation ranges in the low marsh zone, however, are predicted to decrease as much as 55 cm, and could possibly affect low marsh vegetation. Threats beyond the proposed hydrological reconnection that directly impact the plant include competition from non-native species. Thus, monitoring of population viability should continue after reconnection.

INTRODUCTION

Over 90% of California wetlands have been lost since American colonization of San Francisco Bay over 150 years ago (Dahl 1990), placing a premium on wetland preservation and restoration (Project 1999). Wetland restoration - especially for tidal wetlands - can be extremely complex because global warming and sea level rise may compromise the long-term success of restoration efforts (Zedler 2001; Orr, Crooks, and Williams 2003). In the San Francisco Bay, very little opportunity exists to accommodate space for estuarine (or marine) transgression, defined as the net migration of tidal marshes inland with rising sea level, threatening to further reduce wetland habitat (Goals Project 1999; Helley 1979). The restoration of Spring Branch Creek in the Solano Land Trust's Rush Ranch property, however, offers a rare opportunity to reconnect an alluvial fan (Spring Branch Creek) to Suisun Marsh, allowing room for water, plants, and wildlife to migrate landward as sea level rises.

Rush Ranch is a 2000-acre property in Suisun Marsh, located in the San Francisco Bay estuary in Solano County, California (Figure 1) and is owned and operated by Solano Land Trust (SLT). Spring Branch Creek is an alluvial fan that terminates into a first-order tidal creek (First Mallard Slough) at Rush Ranch, and drains a 2,670-acre watershed into Suisun Marsh (Figure 2A and 2B). Approximately 75 years ago (in the 1930s), a farm levee road was constructed across the Spring Branch Creek channel by digging a borrow pit upstream of the levee. In addition, an L-shaped berm was constructed by digging an adjacent borrow ditch. The berm and levee, which cut off tidal flows that historically reached above Grizzly Island road, were constructed in order to create an impoundment for cattle use. An additional levee, constructed to create a cattle impoundment in upper Spring Branch Creek, prevents a greater volume of freshwater flows from entering lower Spring Branch Creek. The present-day alluvial fan within lower Spring Branch Creek is a result of this altered hydrology from the berm levee construction within lower and upper Spring Branch Creek (Brenda Grewell pers. comm.). In the 1990s, SLT installed two four-foot culverts beneath the levee road in an attempt to partially restore the exchange of tidal water with fresh water (Figure 2B & 2C). However, the presence of the ditches and berms and the levee continues to restrict tidal exchange and natural channel formation, highlighting the opportunity for complete hydrological reconnection.

However, with this opportunity there are potential constraints. Specifically, changes in hydrological inundation in lower Spring Branch Creek may impact a population of the federally listed plant soft bird's-beak (*Chloropyron molle* ssp. *molle*, syn., *Cordylanthus mollis* ssp. *mollis*), which was reintroduced to the upstream side of the hydrological impediments in 2000, and now is a thriving population of over 100,000 individuals (B. J. Grewell 2005). The purpose of this project is to (1) understand the tidal inundation depth, frequency, and duration associated with the soft bird's beak and (2) to determine how changes in tidal water elevations following topographic modifications (for restoration) may impact the plant and it's associated vegetation communities.

Soft Bird's Beak Ecological Requirements

Soft bird's beak is a hemi parasite, and is dependent on its host community, the edaphic environment, tidal and seasonal flooding, and bee pollinators (Figure 3). Threats to its resiliency are invasive species and herbivores. Each direct and indirect relationship between dependencies and threats to soft bird's beak is described below.

While the edaphic environment (pathway 1) has a direct relationship to soft bird's beaks survival, this species can survive under a variable soil conditions at Spring Branch Creek (B. Grewell et al. 2003). In the First Mallard Slough (within Suisun Marsh) water column salinity (pathway 1A) is dependent on seasonal flood variation ranges between 1.2-9.0 Parts Per Thousand (PPT) (Lisa Schile pers. com), and has an indirect relationship to soft bird's beak by influencing the pore water salinity present in the edaphic environment. Grewell reports that soil salinity (pore water salinity) can vary between 2.0-10.0 PPT at Spring Branch Creek, with higher soil salinity in bare areas (lacking plant cover) and lower soil salinity in areas with natural plant cover. In fact, salinity was even further reduced when soft bird's beak was present (B. J. Grewell 2008).

Restricted to the high marsh, soft bird's beak relies on a mixed halophyte vegetation host community (pathway 2) with intermediate canopy height and gaps at Spring Branch Creek (B. J. Grewell 2005). Canopy gaps allow the soft bird's beak to photosynthesize on its own, while it receives the other nutrients it requires from the roots of its host community. Soft bird's beak host community is not specific, but at Spring Branch Creek it is frequently found with salt marsh dodder (*Cuscuta* *salina*), salt grass (*Distichlis spicata*), fat hen (*Atriplex triangularis*), sea lavender (*Limonium californicum*), and pickleweed (*Salicornia virginica*) (B. J. Grewell 2005). Diversity of the host community tends to be higher with the presence of soft bird's beak, whereas pickleweed tends to outcompete rarer species (such as *Atriplex prostrate* and *Triglochin maritima*) following decline or removal of soft bird's beak (B. J. Grewell 2008).

There is a combined positive relationship between soft bird's beak and invasive winter annual grasses (pathway 3). Sickle grass (*Hainardia cylindrica*) and rabbitsfoot grass (*Polypogon monspeliensis*) have been linked with seedling mortality at Spring Branch Creek (B. J. Grewell 2005). Similarly, invasion by perennial pepperweed (*lepidium latifolium*) in the high marsh zone is another direct threat. Removal of the hydrological barriers to tidal influence (berms and levee) may improve the soft bird's beak population by creating an unsuitable environment for the invasive annual winter grasses (and potentially perennial pepperweed), thus reducing soft bird's beak seedling mortality at critical life stage (B. J. Grewell 2005). However, this hypothesis will need to be tested in order to determine its validity.

There is also a direct relationship between soft bird's beak and seasonal and tidal flooding (pathway 4). Previous studies have characterized the inundation depth, duration, and frequency between soft bird's beak populations with Spring Branch Creek, Hill Slough, and Benicia (B. Grewell et al. 2003). Yet, these were not tied to specific water elevations and a tidal datum that could transfer findings for spatial assessment. Topography (pathway 4A) is indirectly related soft bird's beak, by providing a slope, gradient and elevation sufficient for tidal or seasonal inundation (B. J. Grewell 2005).

There is direct negative and positive relationship between soft bird's beak and herbivores (pathway 5A and 5B). The endangered salt marsh harvest mouse (*Reithrodontomys raviventris*), for example, eats soft bird's beak seeds (B. J. Grewell 2005). Lastly, there are two direct positive relationships between bee pollinators and soft bird's beak (pathway 6A and 6B). Soft bird's beak requires the bees for pollination and the bees depend on soft bird's beak for food (B. J. Grewell 2005).

This study focuses on understanding the current tidal inundation depth frequency and duration (pathway 4 and 4A) that soft bird's beak is currently thriving under at Spring Branch Creek. A second purpose is to predict how topographic alterations (removal of the Spring Branch Creek berm and levee) (pathway 4A) may change the tidal hydrology and impact the area occupied by soft bird's beak and it's associated vegetation communities. This study does not address how topographic modifications may impact ground water, seasonal fresh water flows, or water column salinity, which may also impact soft bird's beak.

METHODS

I used three methods to characterize the existing tidal hydrology of the area above and below the Spring Branch Creek culverts; I analyzed (1) water elevation, (2) vegetation data, and (3) hypsometric diagrams. Using GIS I modeled future water elevations and predicted vegetation response above the Spring Branch Creek culverts following the removal of berms. Lastly, I conducted field observations at the Spring Branch Creek population and a second population at Benicia State Recreation Area to determine how inundation rates differ between the two sites.

Water Elevation

I collected water level data above and below the culverts at Spring Branch Creek to determine the hydrological conditions under which soft bird's beak is currently thriving. I collected water level data during over a spring and neap tidal cycle at 12-minute intervals using a troll level 500-pressure transducer, from April to September 2011. Spring tidal cycles correspond to tides that occur during new and full moon, where the gravitational pull of the moon and sun to earth is stronger (because the sun, earth, and moon are all in a line), resulting in higher high tides and lower low tides. The neap tides occur when sun and moon are at 45-degree angle to each other, which diminishes the gravitational pull and produces lower high tides and higher low tides. I installed the pressure transducers, housed in a stilling well, using Wetland's and Water Resources specifications (Appendix A). In addition, I attached an L-bracket to the stilling well and surveyed it using an RTK GPS, and tied points to a secondary control benchmark recorded in NAVD 1988 Datum (meters), in order to tie water level data to water elevation.

Every month, I collected calibration readings by direct observation of the water depth in comparison to the reading of the pressure transducer. In addition, I recorded the distance between the stilling well elevation benchmark and the water level to calibrate the relationship between pressure transducer readings and water elevation (Appendix B). I converted water depth readings to water elevation using the relationship established from field measurements between the pressure transducer readings and water elevation (by adding .453 meters to each pressure transducer reading for the station below the culverts and adding 1.043 meters to each pressure transducer reading for the station above the culverts) (Appendix B). For each tidal day (24 hours and 50 minutes), I determined the two peak high tide elevations (higher high water [HHW] and low high water [LHW]), and the two low tide elevations (lower low water (LLW) and high low water [HLW]) (Appendix C & D). I used the highest and lowest elevation value for each tide cycle to define the range of water elevations possible for each tidal cycle. I then calculated the average (mean) water elevation per tidal cycle (Table 1). In addition I calculated the frequency of each tidal event including events above the mean for the highest high tide of the day.

To translate these data for spatial assessment, I developed a water elevation surface model in GIS using a topographic surface model and the high and low values for each of the four tidal water elevations. To do this, I created a ground surface digital elevation model (DEM) of the Spring Branch Creek Watershed, using 2007 DWR LiDAR and RTK GPS ground surveys conducted in 2009 and 3D interpolation of mean tidal stages (Appendix E).

Vegetation & Hypsometric Diagrams

To determine which vegetation types correspond with tidal elevations, I overlaid the Department of Fish and Game and Solano Land Trust vegetation polygon data on the tidal elevation data. Using two digital elevation models (DEMs), derived from ground RTK surveys one for the area above and another for the area below the Spring Branch Creek culverts, I developed two hypsometric diagrams using R package hydroTSM version 0.3-3. The DEM boundary was defined such that only RTK survey data were used (not using LiDAR to ensure accuracy) and that the area above and below the culverts was similar is spatial extent (square meters) and range of elevations (Appendix B, Figure 5). Hypsometric diagrams are used to illustrate the proportional area of a given elevation at a site. On top of the hypsometric curve, I overlaid the elevation locations of each tidal height stage, site features and vegetation community. This shows the current relationship between % area and each factor: ground elevation, water elevation and vegetation

Modeling Future Conditions

To see how water elevations would change following hydrological connection, I reclassified the water surface model above the culverts using the water elevations below the culverts. I assumed that following reconnection (and removal of the berms and levee), tidal inundation conditions would be similar to the area below the culverts. In addition I compared the hypsometric diagram between the area above and below the culverts to help predict how vegetation communities may shift following hydrological reconnection. While salinity is a related factor to future vegetation patterns, these data were not collected. However, I assumed that water column salinities would be similar to the area below the culverts following hydrological reconnection, and data exist for this.

Reference Site Comparison

On November 25th, 2011 I visited the Spring Branch Creek project site and Benicia State Recreation Area to (1) investigate whether the projected high tide inundated the soft bird's beak populations at the two sites (2) to ground-truth the accuracy of the correlation between water inundation and vegetation shown in the hypsometric diagrams and water elevation model. I also collected site photos, and noted the general stature and elevation range occupied by the populations.

RESULTS

Existing Conditions

There is minimal difference between the ranges of high tide elevations seen above and below the culverts: 1.65-2.39 meters for the HHW range below the culverts compared to 1.60-2.33 meters above the culverts (Table 1 and Figure 4). Meanwhile, there is a significant difference between the low water elevations seen above and below the culverts: 0.62-0.84 meters for the LLW range below the culverts compared to 1.17-1.29 meters above the culverts.

The range of spring tide HHW elevations (tidal events during the new and full moon) above the culverts (events between mean HHW [MHHW], or 1.99 meters, and the most extreme spring tide HHW event of 2.3 meters) corresponds almost exactly to the elevation highest and lowest elevation range occupied by soft bird's beak (Figure 5). The range of spring tide HHW elevations below the culverts (2.0-2.4 meters) corresponds to marsh plain vegetation of saltgrass-rush- arrowhead grass-milkwort (Distichlis-Juncus-Triglochin-Glaux) assemblage. In terms of inundation frequency, soft bird's beak was inundated 55% of tidal days for the period of record (80 of 149 tidal days), or .5 times per tidal day, and an average of 2.37 hours per tidal day. The salt grass-rush- arrowhead grass-milkwort assemblage was inundated 63% (93 of 149 tidal days), for 2.86 hours per tidal day on average (Table 2). Spring tide events tend to occur in 2-7 consecutive days in a row followed with 2-12 consecutive days without spring tide events. Below the culverts, the greatest percent area is within this tidal range, whereas narrow band exists above the culvert (figure 6A and 6B).

The elevations between MHHW and MHLW above the culverts (1.7-1.99 meters) and below the culverts (1.74-2.00 meters) correspond to vegetation dominated by cattails (Typha angustifolia) and perennial pepperweed (Lepidium latifolium) (Figure 5). These areas are inundated on average once per tidal day (144 of 149 tidal days), for an average of 5.78 (above culverts) and 5.98 (below culverts) (Table 2). The greatest percent area above the culvert is within this tidal range, whereas a very narrow range is present below the culverts (Figure 6A and 6B). This indicates that the partially muted tidal marsh above the culverts is about .5 meters below elevation of downstream natural tidal marsh plain. This could be from the excavation that occurred in the attempt to create a stockpond, where previous landowners dug a borrow pit upstream of the levee in order to create the levee. Though historical aerial photographs indicate that the digging likely occurred in a small area relative to the larger DEM area used to create the hypsometric diagram. Another possibility is that the area has subsided, where soil has settled downward following the 1930s installation of berms and levees, creating a marsh plain that is lower in elevation than the adjacent natural marsh.

The elevations between MHLW and MLHW above and below the culverts occupy a very narrow range within the tidal channel and channel edge (1.23-1.7 m and 0.85-1.74 m respectively). This area is primarily within the tidal channel and no vegetation is present, however there are some areas where vegetation corresponds to tule (Schoenoplectus acutus). These areas are inundated on average twice per tidal day, for 19.56 (above culverts) and 19.37 (below culverts) hours on average per tidal day. The elevations between MLHW and MLLW are within the tidal channel above (1.16-1.21 m) and below (0.62-0.84 m) the culverts, and no vegetation is present. Water elevations below the MLLW are not present either above or below the culverts because water elevation is lower than existing channel ground surface. The area drains completely and the water level is zero at the MLLW elevations.

Future Conditions

Assuming tidal inundation depth, frequency and duration will be similar to the area below the culverts following removal of berms and levees, Spring Branch Creek will likely experience a slight (5-6 cm) increase in spring tide HHW elevations, and a slight increase in frequency of inundation (13 more tidal days of inundation). This result indicates that hydrological reconnection may have a low or neutral impact to soft bird's beaks livelihood because inundation depth, frequency and duration will not significantly change following reconnection. The low gradient slope of Spring Branch Creek, however, will experience a more dramatic change of up to 55 cm following reconnection; thus HHW tidal range will occupy significantly more space (Figure 7).

The MHHW to MHW range will experience little to no change following reconnection, because the area is lower in elevation than the area downstream, which means the dominate vegetation of cattails and perennial pepperweed will likely remain. Following reconnection, the upstream area may experience better drainage and the water table may drop but cattails are likely to persist (Phil Williams pers. Comm). Lastly, unless a channel is graded at lower elevations or a very large storm event creates a lower elevation channel, there will likely be little to no change in the MHLW to MLHW elevation ranges following reconnection. Water column salinity is not expected to change in Spring Branch Creek following hydrological reconnection, aside from the area that will experience new tidal flows (Figure 7) because of the minimal difference between high water elevations above and below the culverts. However removal of the upstream impoundment may increase freshwater flows to the area negating the affect of increase brackish water. Monitoring during and after the restoration project to evaluate how hydrological changes impact vegetation would be helpful in understanding how and why the site evolves.

Reference Site Comparison

I visited the Rush Ranch site first, arriving at 1:00 PM. The projected high tide for Rush Ranch was 1.88 meters at 1:14 PM according to the closest station, Joice Island Station (ID no. 9415379). The high tide (at time of my observation) reached just below the population, not inundating the population. Since the tide was projected to be within a lower range than the water elevations that correspond to soft bird's beak (1.99-2.3 m), this corresponds with my model results.

I arrived at Benicia at 2:30 PM, 1.5 hours after projected high tide. The projected high tide for Benicia State Recreation area was 1.75 meters at 12:53 PM for Benicia according to the closest station, Port Chicago Station (ID no. 9415144). The high tide was inundating the soft bird's beak populations at the time of my observation. In addition, the Benicia population was far more extensive, occupying a broader range within the marsh plain than the population at Rush Ranch. Further, it was much larger in stature (Appendix F).

The finding that during the same tide cycle, the Benicia population was inundated, while Rush Ranch population was not, indicates that soft bird's beak may be able to persist at higher rates of inundation than currently experienced at Rush Ranch. Supporting this observation, a previous hydrological assessment for the two sites found the Benicia site to have greater inundation frequency compared to Rush Ranch (B. Grewell et al. 2003). The observation that the Benicia population appears more robust than the Rush Ranch population indicates that the environmental conditions (perhaps including hydrological conditions) at Benicia may be more suitable for the bird's beak. Previous studies and observation also suggest that the Benicia population is in better condition than the Rush Ranch population because of the increased frequency of inundation (Brenda Grewell pers. comm.).

However, this comparison can only have limited value considering the projected tides were reported in a different Datum than Rush Ranch water elevations- predictions are relative to MLLW rather than to NAVD 88 as the Spring Branch Creek water elevations are. In addition, since this observation did not occur while I was actively collecting data at Spring Branch Creek, I cannot adequately test the water surface model projections.

DISCUSSION

Tidal hydrological analysis indicates that soft bird's beak has a hopeful future considering planned hydrological reconnection. However, there is limitation in reviewing only tidal hydrological changes in considering whether hydrological reconnection will impact the soft bird's beak. Because tidal water elevation data was only collected for a six-month period, inter-annual variability and fresh-water inputs were not adequately captured. Future studies that examine the relationship between soft bird's beak and the inter-annual variation of rainfall and seasonal (freshwater) inputs, ground water and salinity would strengthen this study.

Changes in hydrology are not the only potential threat that directly impacts the soft bird's beak. In fact, the soft bird's beak population in Spring Branch Creek has experienced decline in recent years (B. J. Grewell 2005). Soft bird's beak appears to be most vulnerable at the emergent seedling stage when unsuitable hosts, exotic winter annual grasses, are present (B. J. Grewell 2005), causing seedling mortality. The decline may also be associated with an inadequate host population that may not be able support the growing hemiparasite population (B. J. Grewell 2005). In fact, host community die back has been observed in areas with the highest bird's beak establishment (B. J. Grewell 2005).

Management action may be required to ensure the sustainability of the population of soft bird's beak in Spring Branch Creek. Previous studies suggest that removal of the hydrological barriers may improve the soft bird's beak population by creating an unsuitable environment for the invasive annual winter grasses and by reducing soft bird's beak seedling mortality at critical life stage (B. J. Grewell 2005). However, this may not be the case because it appears the inundation rates for winter annual grasses elevations will not shift significantly. If hydrological reconnection does not cause a reduction in this species population, control of these weeds may be necessary. Control efforts will likely be most affective in the late winter, while soft bird's beak and other native perennial marsh plants are dormant but winter annual grasses are growing (B. J. Grewell 2005). Additional weed species Celery (Apium graveolens) perennial pepperweed, which tends to co-invade, may further threaten soft bird's beak and a combine control strategy is recommended.

Sea level rise and estuarine transgression, however, may further threaten the species. The species may need to adapt by shifting up slope and up the Spring Branch Creek gradient. According to Wetlands and Water Resource's Rush Ranch Existing Conditions Report, Spring Branch Creek, with active alluvial fans and gentle slopes, will be particularly well suited to accommodate estuarine transgression (WWR 2010). In addition, non profit group PRBO Conservation Science developed a web tool showing projected changes in elevation under 0.52 and 1.65-meter sea level rise scenarios (Veloz 2011). The website offers an interactive feature where one can see projections with low and high sediment availability and low and high accumulation of organic material. A commonality among all sediment and organic matter accumulation scenarios is that high marsh elevations (which would be potential soft bird beak habitat) will become less prevalent in lower Spring Branch Creek and more prevalent in upper Spring Branch Creek. Since soft bird's beak habitat will likely need to shift up the Spring Branch Creek gradient as sea level rises, management and restoration actions should ensure all physical impediments are removed that may prevent migration from occurring. Long term monitoring will also help determine whether assisted migration is necessary or whether the species can migrate on it's own.

CONCLUSION

Reconnection of Spring Branch Creek to full tidal influence from Suisun Marsh will not significantly change the hydrological conditions that soft bird's beak is currently thriving under. Nonetheless management actions are necessary to ensure the long-term survival of the species as threats from other plants ensue. Sea level rise and estuarine transgression may further threaten the species if the soft bird's beak is unable to migrate landward and up the Spring Branch Creek gradient on its own. With careful monitoring, land managers should be able to detect whether the species is able to migrate on its own or if assisted migration up slope or up the Spring Branch Creek gradient is necessary.

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TABLE 1: TIDAL WATER ELEVATION RANGES

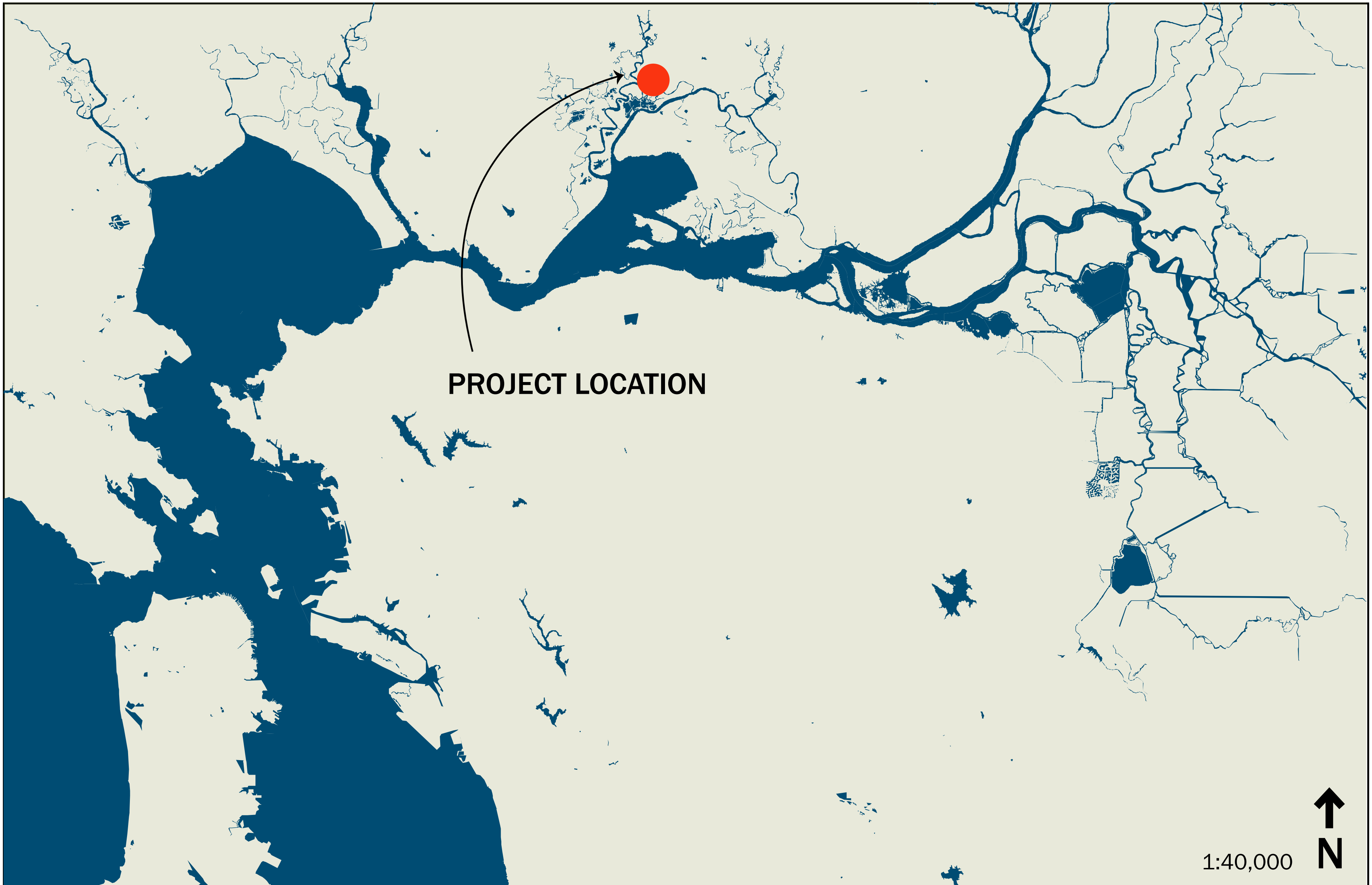
Tidal Cycle	Minimum	Maximum	Mean	Date of Maximum
Below Culvert				
HHW	1.65	2.39	2.03	5/17/11
LHW	1.42	2.00	1.74	5/16/11
LLW	0.62	0.84	0.68	4/30/11
HLW	0.62	1.19	0.85	4/29/11
Above Culvert				
HHW	1.60	2.33	1.99	5/17/11
LHW	1.37	1.96	1.69	5/16/11
LLW	1.17	1.29	1.21	8/17/11, 8/18/11, 8/23/11
HLW	1.17	1.31	1.23	8/18/11, 8/22/11

Notes: All units are in meters (NAVD 88). For each diurnal tidal cycle (24 hours and 50 minutes), I determined the two peak high tide elevations (higher high water [HHW] and low high water [LHW]), and the two low tide elevations (lower low water [LLW] and high low water [HLW]) (Appendix C & D). I used the highest and lowest elevation value for each tide stage to define the range of water elevations possible for each tidal stage. I then calculated the average (mean) water elevation per tidal stage.

TABLE 2: TIDAL DURATION AND FREQUENCY

Tidal Stage Range	Duration (no. hours per tidal day)	Frequency (no. days)	Frequency (no. times per day)	Associated Vegetation
Below culvert				
Above MHHW	2.86	93	0.6 (60%)	salt grass-rush-arrowhead-milkwort
Above MHLW	5.98	144	1 (100%)	Cattails and perennial pepperweed
Above MLHW	19.37	149	2 (200%)	Tule
Above culvert				
Above MHHW	2.37	80	0.5 (50%	Soft bird's beak and host community
Above MHLW	5.78	144	1 (100%)	Cattails and perennial pepperweed
Above MLHW	19.56	149	2 (200%)	Tule

Notes: Duration is reported as the average number hours inundated per tidal day for the days it is inundated. Frequency is reported as number of days inundated for the period of record (149 days) and the average number times inundated per tidal day.



REGIONAL LOCATION MAP

Notes:
Map created uses ESRI and Adobe Illustrator software by Jessie Olson. Data source: CalAtlas http://atlas.ca.gov/

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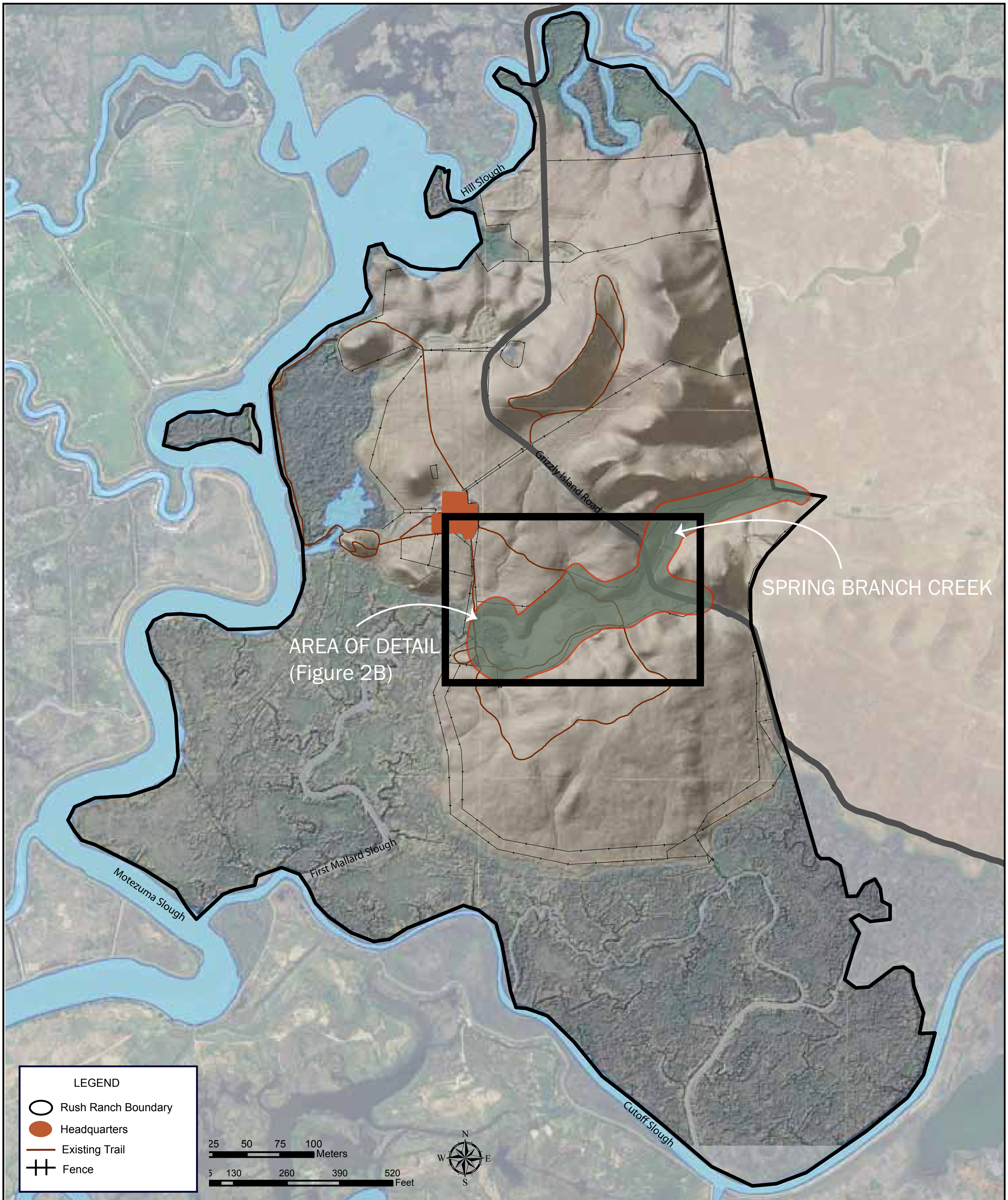
Figure 1



RUSH RANCH

Notes: Map created using ESRI and Adobe Illustrator software by Jessie Olson. Hillshade created from DWR 2007 LiDAR. Arieal image 2009 NAIP. All other data from Solano Land Trust.

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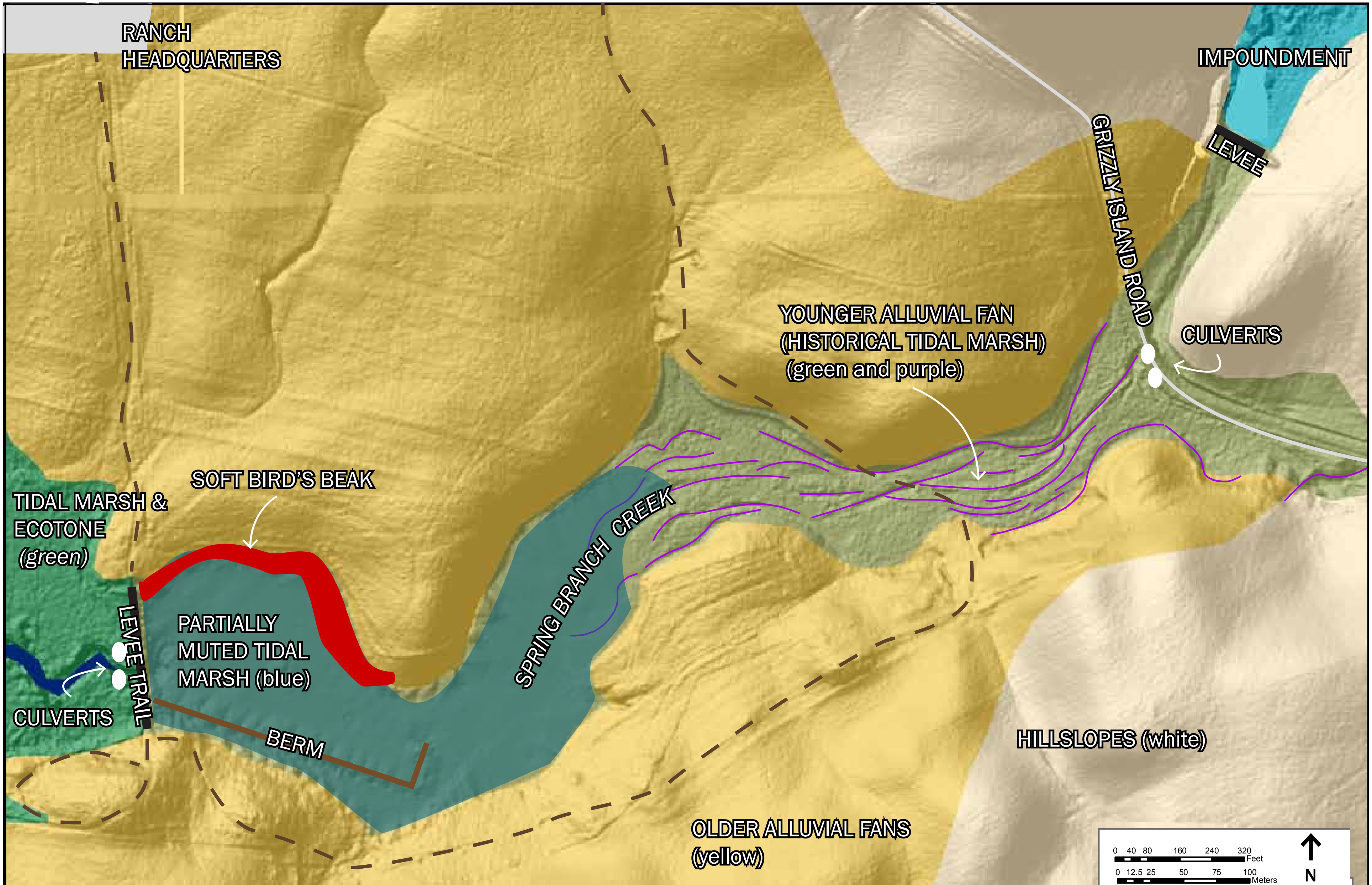
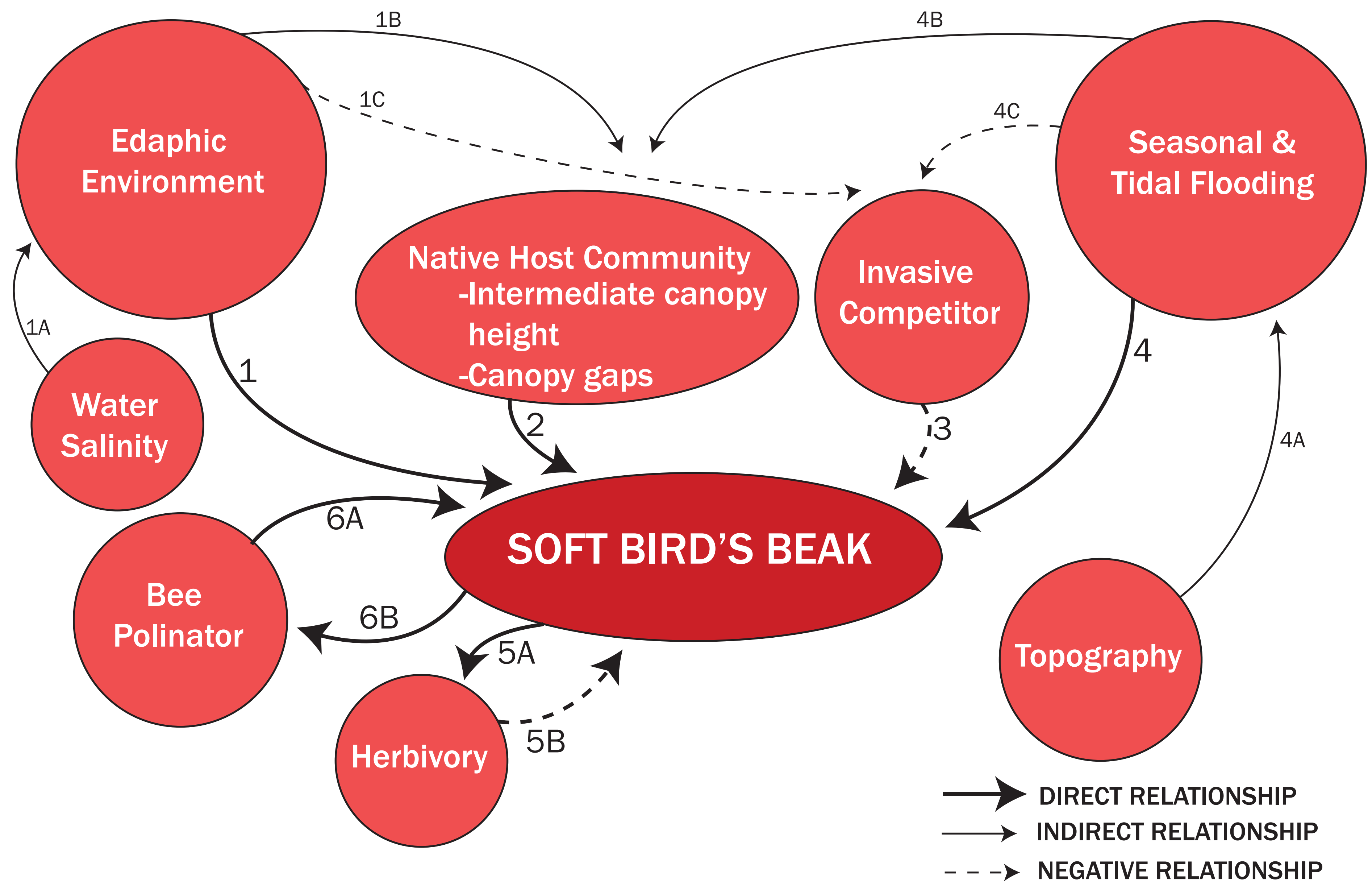
Figure 2A



LOWER SPRING BRANCH CREEK EXISTING SITE FEATURES

Notes: Map created using ESRI and Adobe Illustrator software by Jessie Olson. Tidal range shown in Spring Branch Creek reflects a priori assumption. See Figure 5 and 7 for measured tidal ranges. Ecogeomorphic unit classification (alluvial fan, older alluvial fan, hillslopes) provided by Wetlands and Water Resources. Hillshade derrived from 2007 DWR LiDAR. A ll other data produced by Jessie Olson.	December 2011	**Figure 2B**

SITE PHOTO OF LOWER SPRING BRANCH CREEK LEVEE		
Notes: Looking north at lower Spring Branch Creek levee. Photo taken by Jessie Olson	December 2011	**Figure 2C**



CONCEPTUAL MODEL FOR SOFT BIRD'S BEAK ECOLOGICAL REQUIREMENTS

Notes: Created by Jessie Olson based on the following data sources: (1) Grewell, B., M. DaPratro, P. Hyde, and E. Rejmankova. 2003. "Reintroduction of Endangered Soft Bird's Beak (Cordylanthus mollis ssp. mollis) to Restored Habitat in Suisun Marsh." Final Report for CALFED Ecosystem Restoration Project. (2) Grewell, B.J. 2005. "Population census and status of the endagnered soft bird's-beak (Cordylanthus mollis ssp. mollis) at Benicia State Recreation Area and Rush Ranch in Solano County, California." Report for Solano County Water Agency, Solano County Endangerred Species Conservation Program (3) Grewell, B.J. 2008. "Hemiparasites generate environmental heterogeneity and enhance species coexistence in salt marshes." Ecological Applications 18 (5): 1297–1306.

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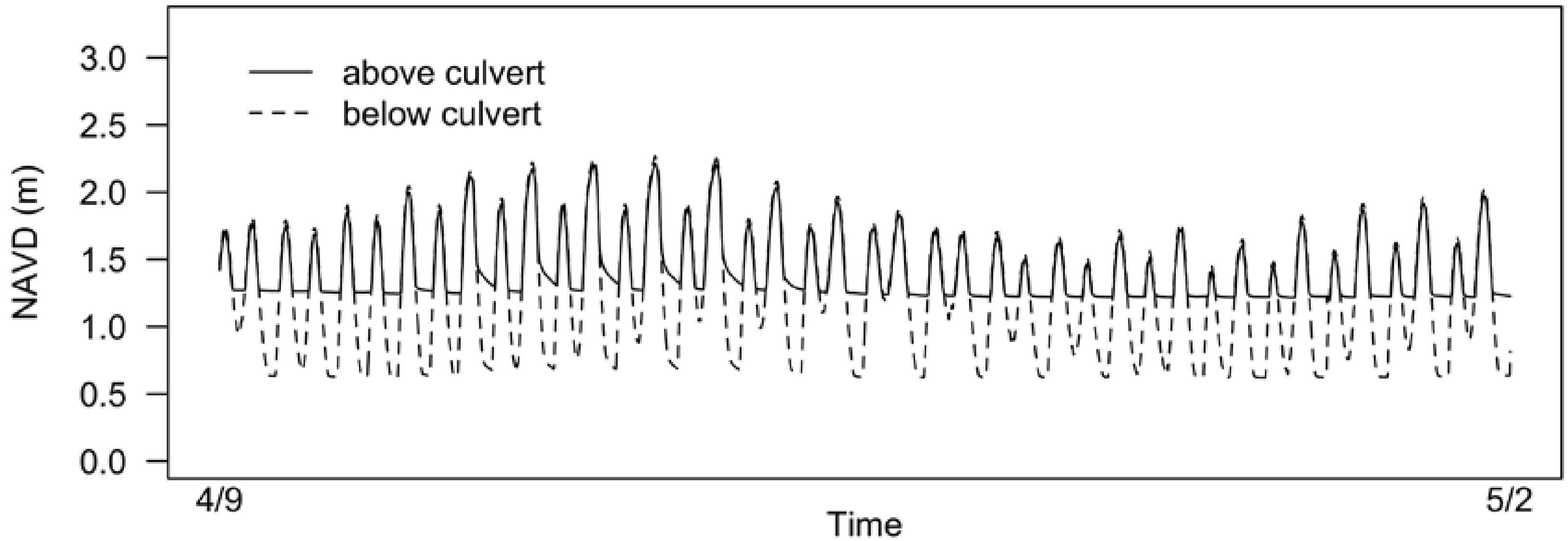
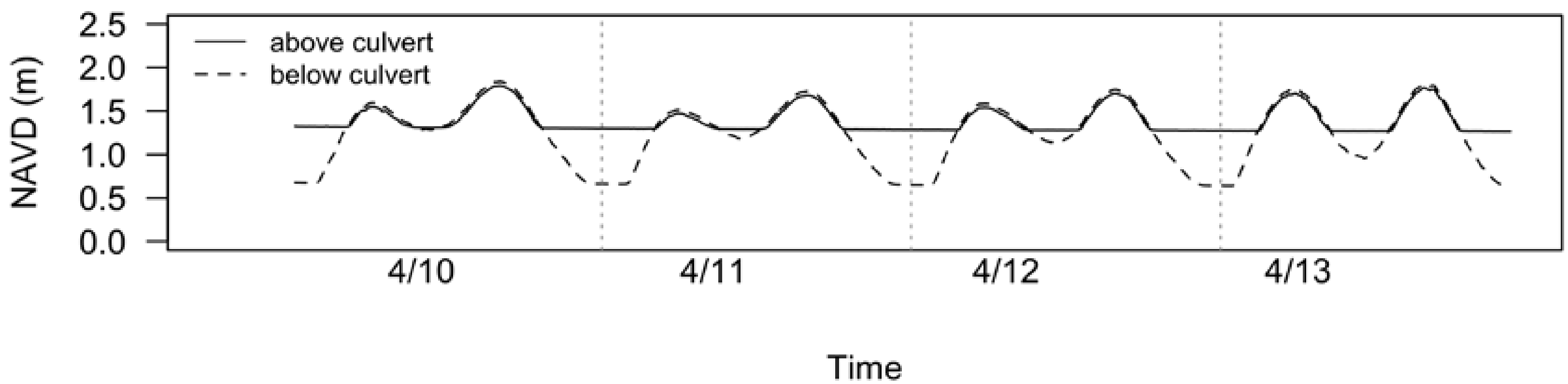
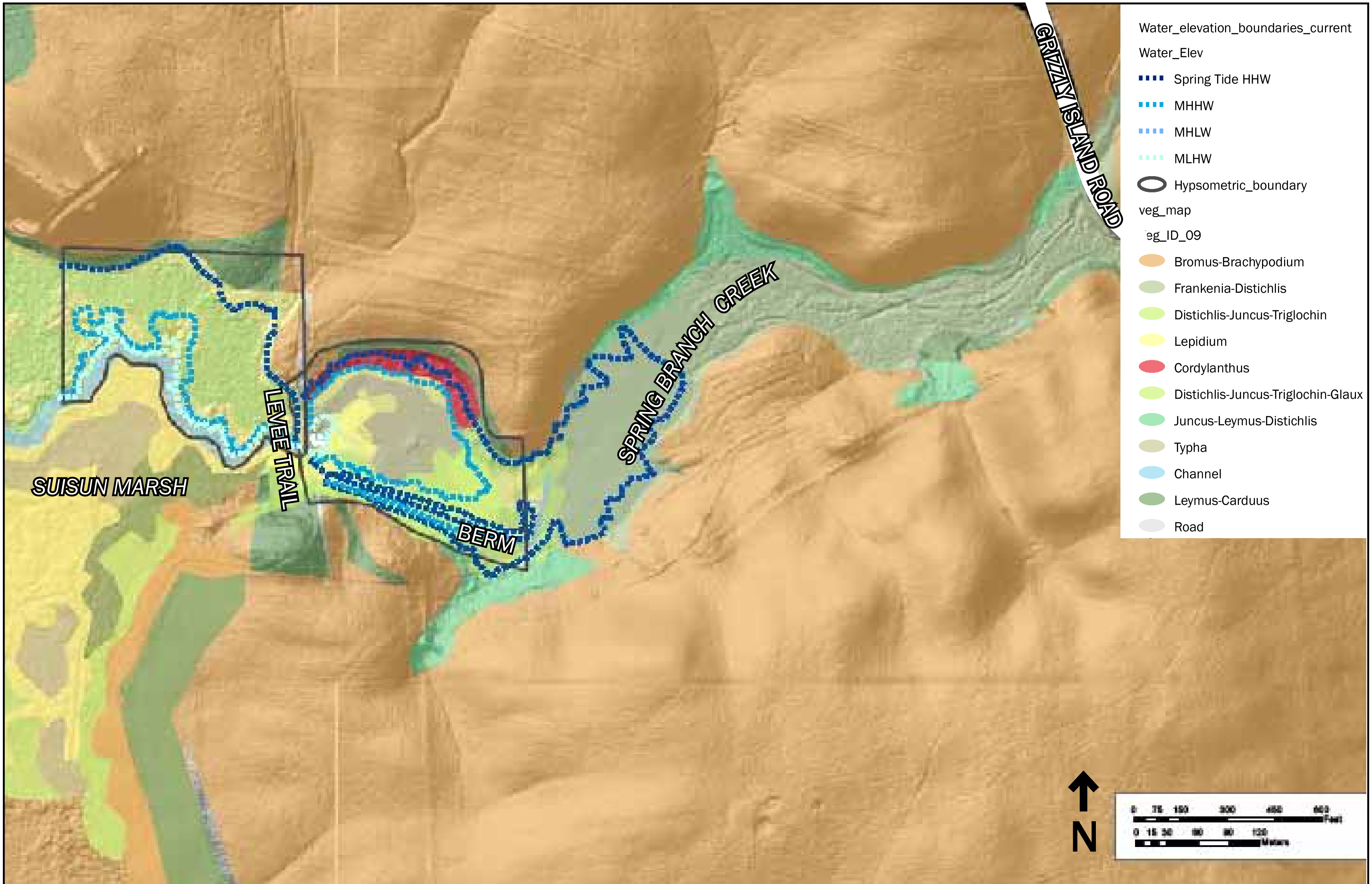
Figure 3





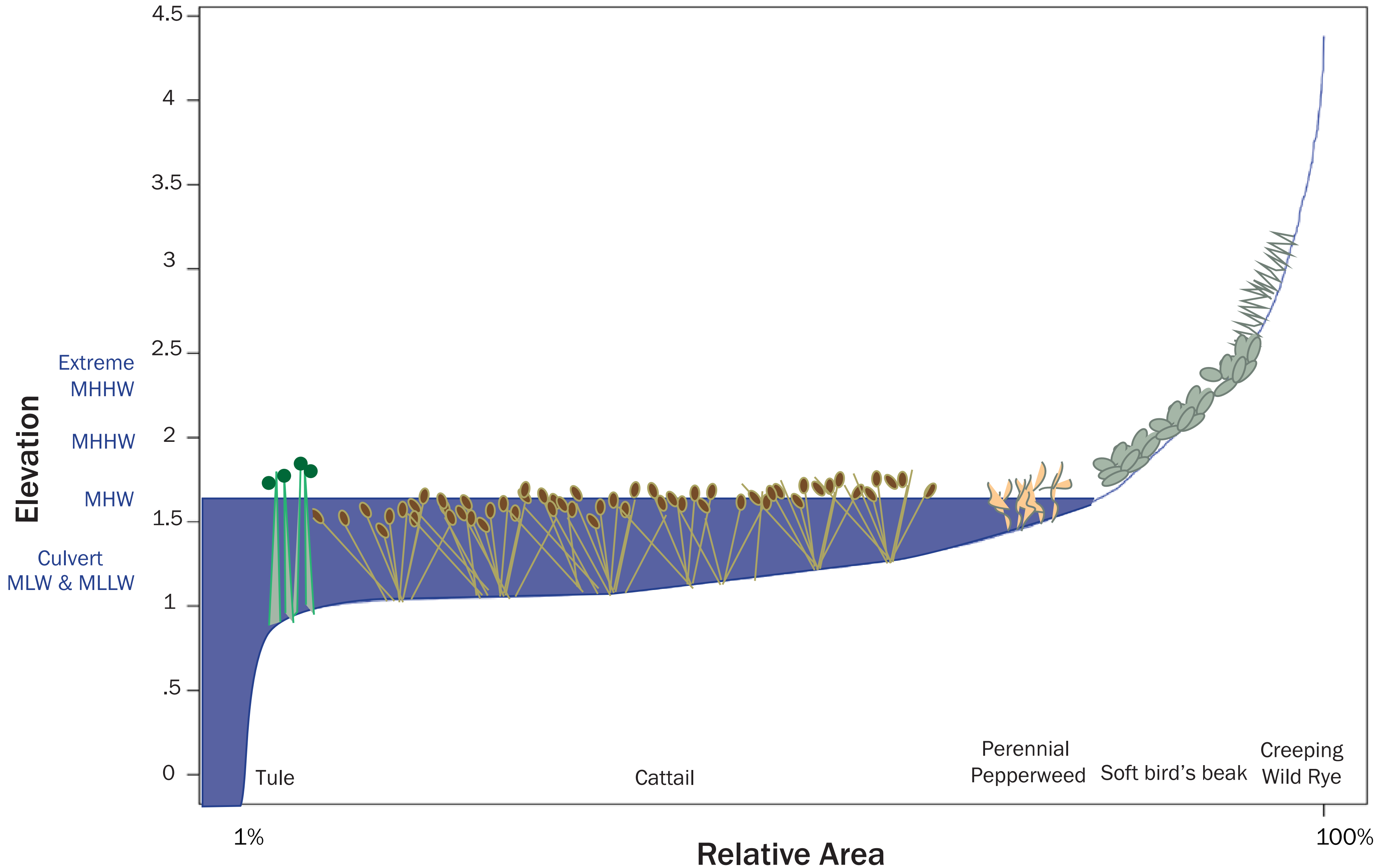
WATER ELEVATIONS ABOVE AND BELOW CULVERTS AT SPRING BRANCH CREEK

Notes: Figure generated by Jessie Olson using R package hydroTSM version 0.3-3. Figure does not included data for entire period of record for display purposes. Tidal day indicated by grey dashed line on lower figure.	December 2011	**Figure 4**



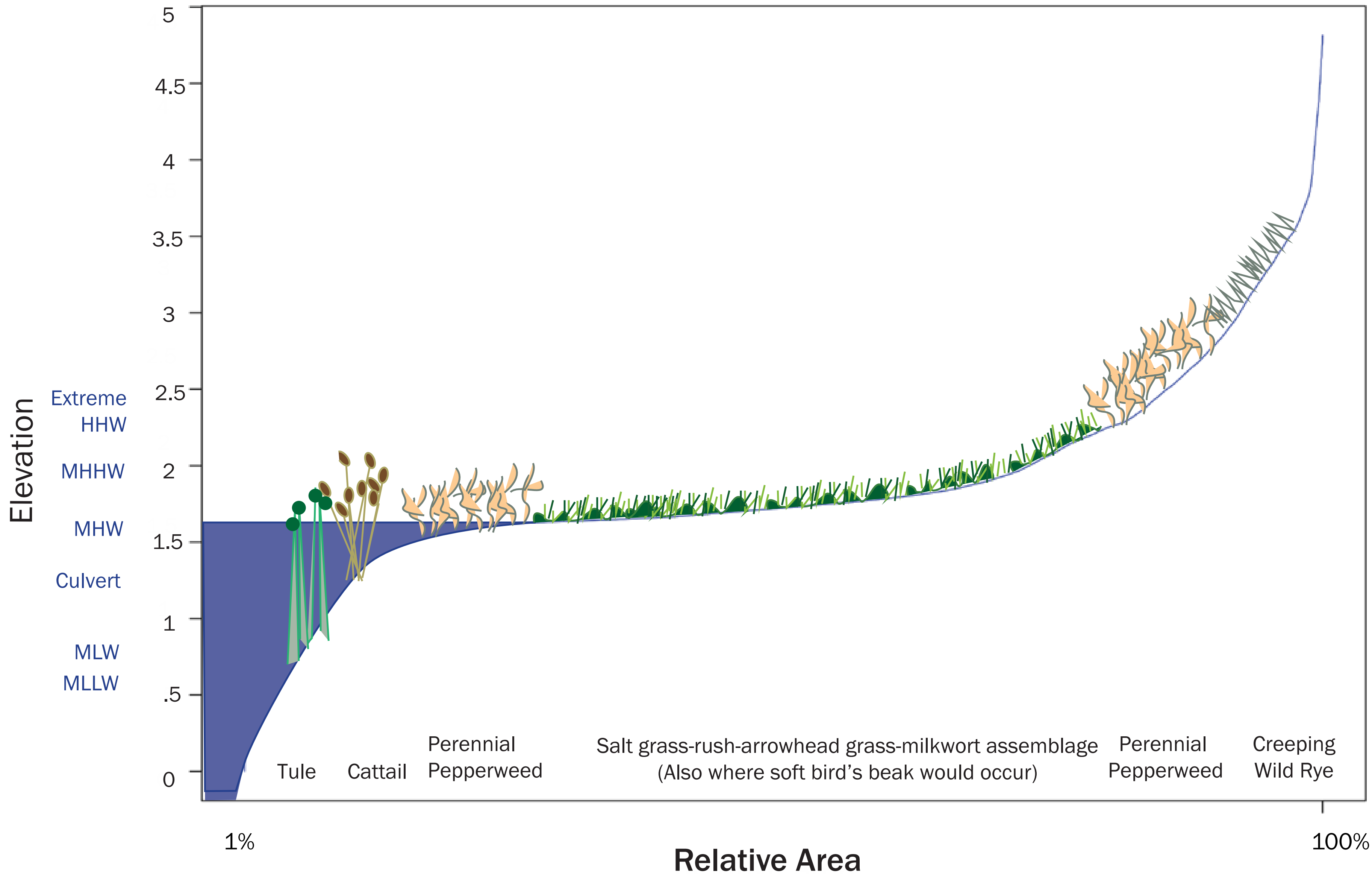
WATER ELEVATION AND VEGETATION: EXISTING CONDITIONS

Notes: Map produced using ESRI and Adobe Illustrator software by Jessie Olson. Vegetation data from Solano Land Trust and Department of Fish and Game. Vegetation sub-associations as classified by Department of Fish and Game were grouped to broader associations for display purposes. Water elevation current conditions created by reclassifying a Digital Elevation Model (DEM) derived from DWR LiDAR and RTK ground sureys.	December 2011	**Figure 5**



HYPOSMETRIC DIAGRAM OF AREA ABOVE CULVERTS

Notes: Hypsometric diagrams developed by Jessie Olson using R package hydroTSM version 0.3-3. The DEM boundary was defined to only use RTK survey data (LiDAR data was found to be up to .5 meters higher than actual ground surface) and to have similar spatial extent (square meters) and range of elevations (Appendix B, Figure 5) between the two locations. Vegetation and water elevation information was aquired from figure 5.	December 2011	**Figure 6A**

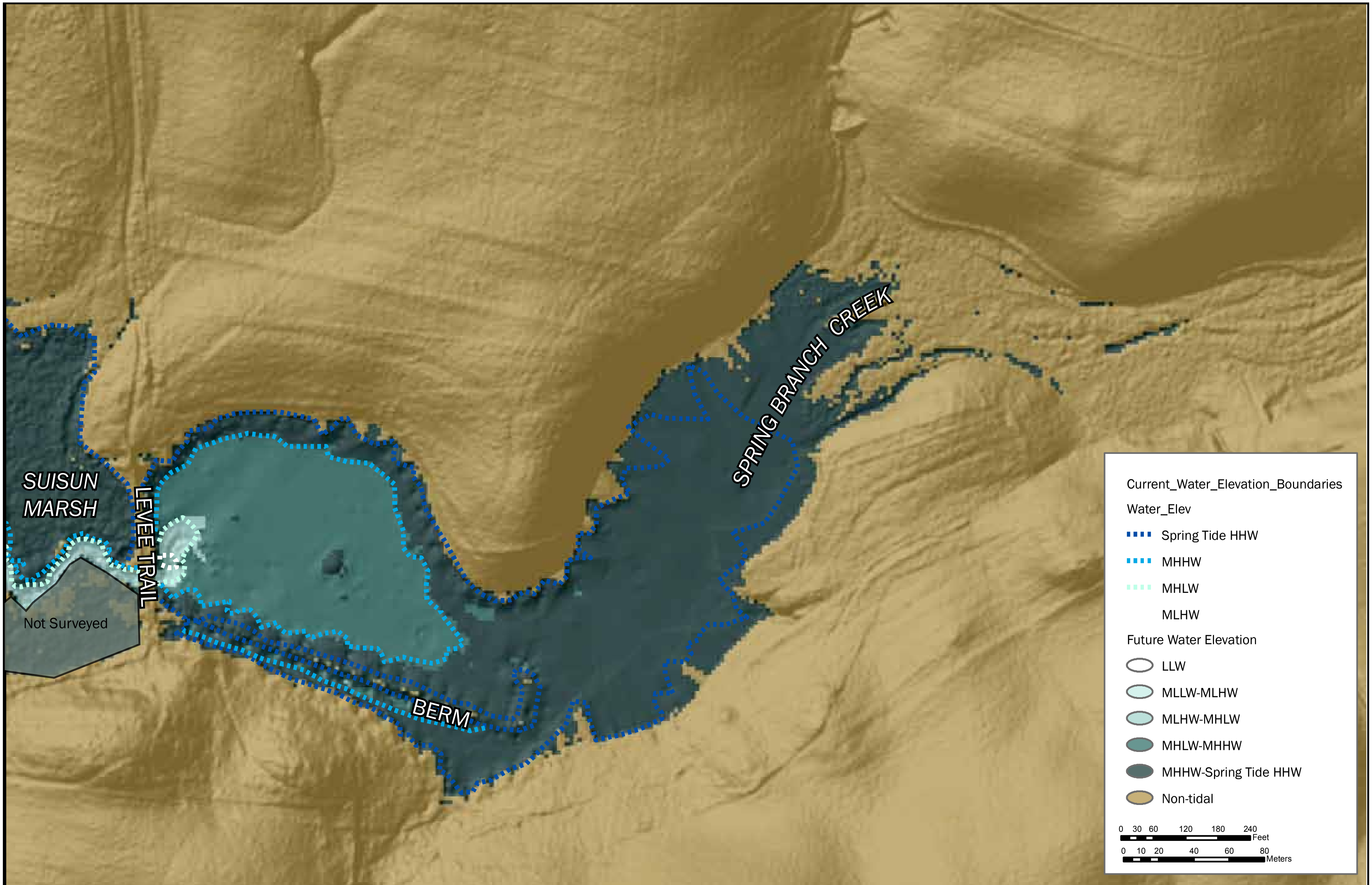


HYPSOMETRIC DIAGRAM OF AREA BELOW CULVERTS

Notes: Hypsometric diagrams developed by Jessie Olson using R package hydroTSM version 0.3-3. The DEM boundary was defined to only use RTK survey data (LiDAR data was found to be up to .5 meters higher than actual ground surface) and to have similar spatial extent (square meters) and range of elevations (Appendix B, Figure 5) between the two locations. Vegetation and water elevation information was aquired from figure 5.

December 2011

Figure 6B



CURRENT AND FUTURE TIDAL WATER ELEVATIONS FOR LOWER SPRING BRANCH CREEK

Notes: Map created using ESRI and Adobe Illustrator software by Jessie Olson. Water elevation projections created by reclassifying a Digital Elevation Model (DEM) derived from DWR LiDAR and RTK ground sureys. In marsh habitats DEM accuracy is limited to the areas where ground survey was conducted. Marsh areas that were not surveyed are indicated on the figure. Hillshade derived from LiDAR and RTK survey DEM.

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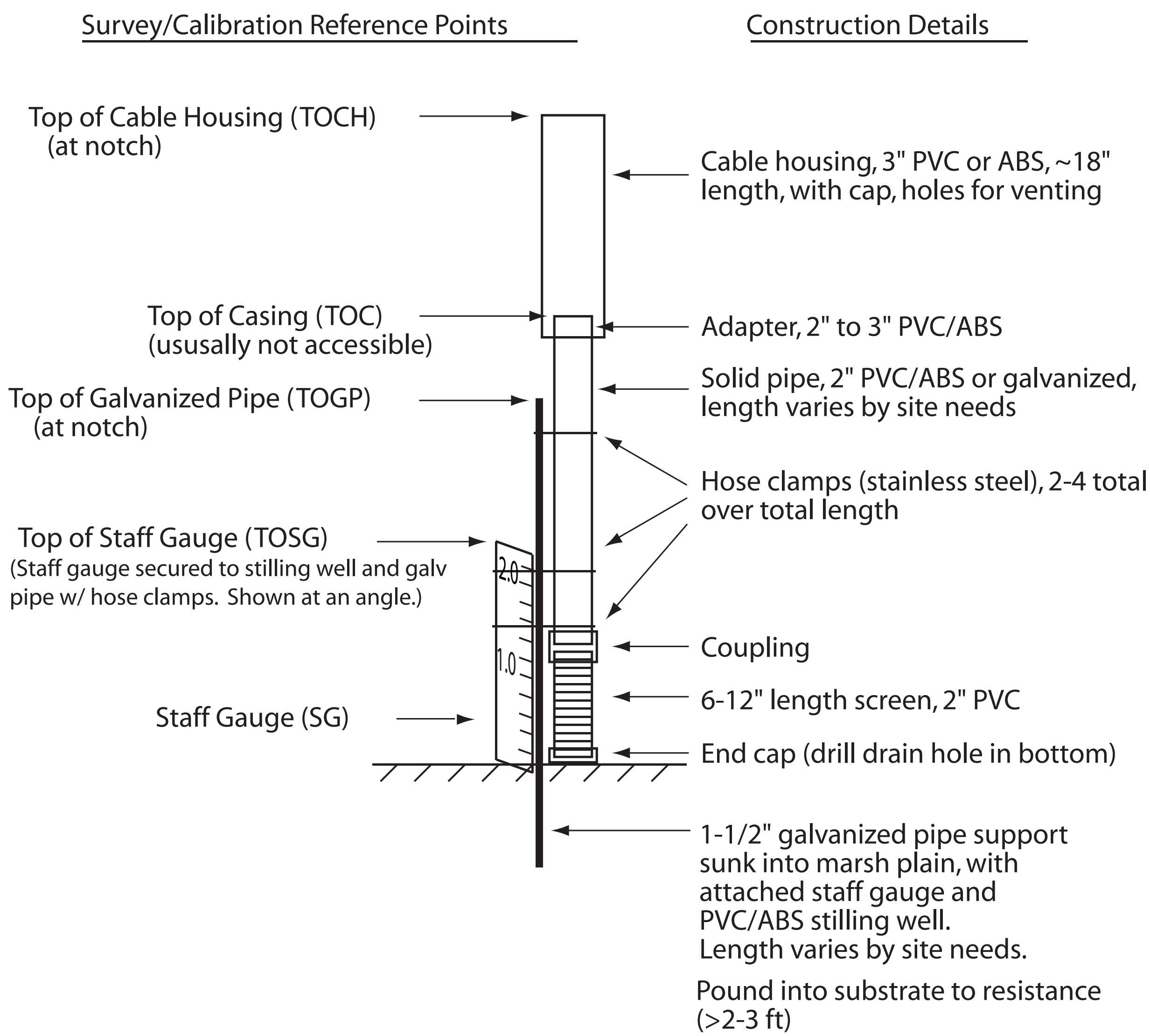
Figure 7

APPENDIX A: STILLING WELL DESIGN SPECIFICATION



WETLANDS AND WATER RESOURCES, INC.

MARSH PLAIN WATER LEVEL STATION SCHEMATIC

Integrated Regional Wetland Monitoring Pilot Project
California Bay-Delta Authority Science Program

December 2006	Project No. 1067	**Figure 5.2**

Marsh plain WL station_1067-2007-0104dg.pdf

RUSH RANCH
Notes: Looking downstream at stilling well below culverts

RUSH RANCH
Notes: Looking upstream at stilling well above culverts.

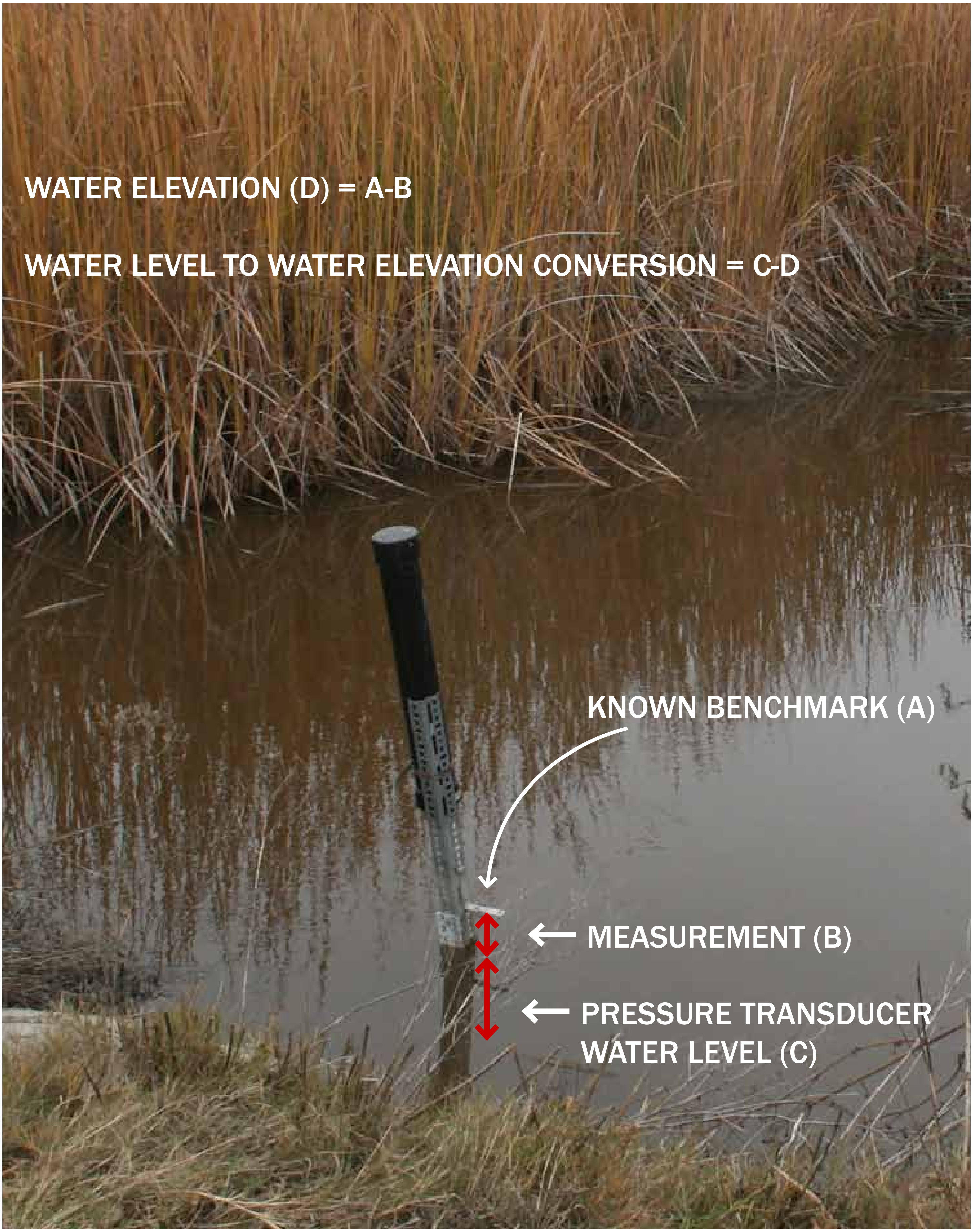
APPENDIX B: WATER LEVEL TO WATER ELEVATION OFF-SET CALIBRATION

APPENDIX B: WATER LEVEL TO WATER ELEVATION OFF SET CALCULATIONS

BELOW CULVERT		A	B	C (A-B)	D	E (C-D)
Date	Time	Bench Mark Elevation (m)	Water Level to Bench Mark-measured (m)	Water Level Elevation (m)	Pressure Transducer	Delta (m)
4/7/11	10:37	2.177	1.279	0.885	0.433	0.452
4/7/11	10:38	2.177	1.279	0.898	0.445	0.453
4/7/11	10:39	2.177	1.279	0.910	0.448	0.462
5/3/11	10:30	2.177	1.600	0.577	0.135	0.442
5/3/11	10:31	2.177	1.600	0.577	0.135	0.442
5/3/11	10:32	2.177	1.600	0.577	0.134	0.443
5/18/11	12:32	2.177	1.460	0.717	0.253	0.464
5/18/11	12:33	2.177	1.460	0.717	0.253	0.464
5/18/11	12:34	2.177	1.460	0.717	0.253	0.464
6/15/11	8:47	2.177	1.460	0.717	0.271	0.446
6/15/11	8:49	2.177	1.460	0.727	0.270	0.456
6/15/11	8:50	2.177	1.460	0.721	0.269	0.453
7/13/11	17:27	2.177	0.818	1.360	0.916	0.444
7/13/11	17:30	2.177	0.818	1.363	0.900	0.462
7/13/11	17:31	2.177	0.818	1.356	0.898	0.457
8/24/11	9:32	2.177	1.132	1.018	0.576	0.442
8/24/11	9:35	2.177	1.132	1.058	0.594	0.464
8/24/11	9:37	2.177	1.132	1.045	0.601	0.443
AVERAGE (OFFSET)						0.453

APPENDIX B: WATER LEVEL TO WATER ELEVATION OFF SET CALCULATIONS

ABOVE CULVERT						
		A	B	C (A-B)	D	E (C-D)
Date	Time	Bench Mark Elevation (m)	Water Level to Bench Mark-measured (m)	Water Level Elevation (m)	Pressure Transducer water level (m)	Delta (m)
4/9/11	1:43	2.081	0.762	1.319	0.269	1.051
4/9/11	1:44	2.081	0.762	1.319	0.269	1.050
4/9/11	1:45	2.081	0.762	1.319	0.269	1.050
5/3/11	10:40	2.081	0.850	1.231	0.175	1.056
5/3/11	10:41	2.081	0.850	1.231	0.205	1.026
5/3/11	10:42	2.081	0.850	1.231	0.174	1.056
5/18/11	12:36	2.081	0.710	1.371	0.357	1.014
5/18/11	12:37	2.081	0.710	1.371	0.327	1.044
5/18/11	12:38	2.081	0.710	1.371	0.327	1.044
6/15/11	8:55	2.081	0.717	1.364	0.322	1.044
6/15/11	8:57	2.081	0.717	1.364	0.321	1.043
6/15/11	8:58	2.081	0.717	1.364	0.320	1.044
7/13/11	17:36	2.081	0.770	1.311	0.282	1.043
7/13/11	17:39	2.081	0.770	1.311	0.265	1.035
7/13/11	17:40	2.081	0.770	1.311	0.264	1.043
8/24/11	9:45	2.081	0.911	1.170	0.124	1.046
8/24/11	9:46	2.081	0.911	1.170	0.123	1.036
8/24/11	9:47	2.081	0.911	1.170	0.123	1.057
AVERAGE (OFFSET)						**1.043**


WATER ELEVATION (D) = A-B
WATER LEVEL TO WATER ELEVATION CONVERSION = C-D
KNOWN BENCHMARK (A)
MEASUREMENT (B)
PRESSURE TRANSDUCER WATER LEVEL (C)

APPENDIX C: DAILY PEAKS BELOW CULVERTS

Appendix C: BELOW CULVERT PEAKS

	LW	HW	LW	HW	date
1	0.6587072	1.5158048	1.1844872	1.7248976	4/10/11 14:30
2	0.6489536	1.5837752	1.1372432	1.7480624	4/11/11 15:18
3	0.640724	1.7498912	0.9540584	1.8099368	4/12/11 16:18
4	0.6343232	1.791344	0.6715088	1.730384	4/13/11 17:06
5	0.6273128	1.9032056	0.628532	1.8303584	4/14/11 17:54
6	0.6221312	2.042804	0.6373712	1.9059488	4/15/11 18:42
7	0.627008	2.160152	0.6782144	1.954412	4/16/11 19:30
8	0.66206	2.2208072	0.6855296	1.9434392	4/17/11 20:18
9	0.759596	2.253116	0.68492	1.9068632	4/18/11 21:18
10	0.8827352	2.2643936	0.6885776	1.9251512	4/19/11 22:06
11	1.0409264	2.250068	0.6815672	1.8010976	4/20/11 22:54
12	0.9949016	2.080904	0.6495632	1.7733608	4/21/11 23:42
13	1.1064584	1.9684328	0.6257888	1.770008	4/23/11 0:30
14	1.1930216	1.8708968	0.6221312	1.7590352	4/24/11 1:18
15	1.0546424	1.724288	0.6227408	1.718192	4/25/11 2:18
16	0.8949272	1.541408	0.6221312	1.6718624	4/26/11 3:06
17	0.788552	1.5115376	0.622436	1.7163632	4/27/11 3:54
18	0.6446864	1.5618296	0.6629744	1.7678744	4/28/11 4:42
19	0.6230456	1.4508824	0.622436	1.648088	4/29/11 5:30
20	0.6203024	1.4816672	0.6449912	1.824872	4/30/11 6:18
21	0.6221312	1.567316	0.7562432	1.9120448	5/1/11 7:18
22	0.6242648	1.6258376	0.8284808	1.9617272	5/2/11 8:06
23	0.6294464	1.6639376	0.9007184	2.0217728	5/3/11 8:54
24	0.6364568	1.6971608	1.0040456	2.0278688	5/4/11 9:42
25	0.645296	1.7099624	1.0671392	2.038232	5/5/11 10:30
26	0.6462104	1.7477576	1.1549216	2.0470712	5/6/11 11:18
27	0.649868	1.7815904	1.1753432	2.039756	5/7/11 12:18
28	0.6477344	1.777628	1.1704664	1.838588	5/8/11 13:06
29	0.6382856	1.7255072	1.075064	1.742576	5/9/11 13:54
30	0.6395048	1.8026216	0.9632024	1.738004	5/10/11 14:42
31	0.6434672	1.9001576	0.7208864	1.6941128	5/11/11 15:30
32	0.6459056	1.9553264	0.6489536	1.7005136	5/12/11 16:18
33	0.6446864	2.1040688	0.6855296	1.8260912	5/13/11 17:18
34	0.6739472	2.236352	0.7239344	1.9089968	5/14/11 18:06
35	0.7766648	2.236352	0.7172288	1.8955856	5/15/11 18:54
36	0.8711528	2.3457752	0.7434416	2.0004368	5/16/11 19:42
37	1.0345256	2.3914952	0.7562432	1.9379528	5/17/11 20:30
38	0.9994736	2.2765856	0.7211912	1.8977192	5/18/11 21:18
39	0.9991688	2.1747824	0.6907112	1.853828	5/19/11 22:18
40	1.0534232	2.080904	0.668156	1.8587048	5/20/11 23:06
41	1.0869512	1.9538024	0.6431624	1.8550472	5/21/11 23:54
42	1.094876	1.7788472	0.6416384	1.7575112	5/23/11 0:42
43	0.9476576	1.5484184	0.6373712	1.7590352	5/24/11 1:30

	LW	HW	LW	HW	date
44	0.8470736	1.497212	0.6748616	1.7742752	5/25/11 2:18
45	0.6571832	1.41644	0.681872	1.8257864	5/26/11 3:18
46	0.64682	1.4725232	0.7912952	1.8931472	5/27/11 4:06
47	0.6459056	1.5447608	0.8751152	1.9794056	5/28/11 4:54
48	0.645296	1.5804224	0.9123008	1.9845872	5/29/11 5:42
49	0.6459056	1.6304096	0.9525344	2.0492048	5/30/11 6:30
50	0.6516968	1.6965512	0.9976448	2.090048	5/31/11 7:18
51	0.6821768	1.738004	0.9888056	2.087	6/1/11 8:18
52	0.6751664	1.6904552	0.979052	2.0754176	6/2/11 9:06
53	0.6745568	1.7355656	1.0326968	2.0745032	6/3/11 9:54
54	0.6968072	1.8318824	1.0723208	2.068712	6/4/11 10:42
55	0.680348	1.8145088	1.061348	2.0318312	6/5/11 11:30
56	0.6672416	1.8215192	0.9619832	1.8620576	6/6/11 12:18
57	0.648344	1.914788	0.934856	1.7687888	6/7/11 13:18
58	0.645296	1.9717856	0.7760552	1.6718624	6/8/11 14:06
59	0.6462104	2.0254304	0.6593168	1.6322384	6/9/11 14:54
60	0.6602312	2.0964488	0.6965024	1.6721672	6/10/11 15:42
61	0.8214704	2.1854504	0.7190576	1.7514152	6/11/11 16:30
62	0.9223592	2.2293416	0.7254584	1.779152	6/12/11 17:18
63	0.95924	2.2448864	0.7221056	1.7931728	6/13/11 18:18
64	0.9659456	2.265308	0.7266776	1.8489512	6/14/11 19:06
65	1.03544	2.28512	0.7370408	1.9272848	6/15/11 19:54
66	1.0677488	2.2747568	0.7330784	1.9699568	6/16/11 20:42
67	1.0845128	2.1973376	0.7114376	1.9580696	6/17/11 21:30
68	1.0805504	2.1095552	0.6855296	1.9138736	6/18/11 22:18
69	1.04306	1.958984	0.6553544	1.9233224	6/19/11 23:18
70	1.0805504	1.7986592	0.6532208	1.933076	6/21/11 0:06
71	1.0845128	1.6712528	0.6934544	1.9541072	6/22/11 0:54
72	0.9406472	1.5222056	0.817508	1.9157024	6/23/11 1:42
73	0.7678256	1.4231456	0.8854784	1.937648	6/24/11 2:30
74	0.6657176	1.4615504	1.0351352	1.9836728	6/25/11 3:18
75	0.6623648	1.5267776	1.0921328	2.0111048	6/26/11 4:18
76	0.6648032	1.6407728	1.1719904	2.1001064	6/27/11 5:06
77	0.6931496	1.7413568	1.1768672	2.1574088	6/28/11 5:54
78	0.7114376	1.7407472	1.1216984	2.1485696	6/29/11 6:42
79	0.7068656	1.7514152	1.072016	2.1552752	6/30/11 7:30
80	0.7059512	1.792868	1.0540328	2.1881936	7/1/11 8:18
81	0.7114376	1.87364	1.0497656	2.181488	7/2/11 9:18
82	0.70778	1.9175312	0.9997784	2.11748	7/3/11 10:06
83	0.70016	1.9495352	0.9507056	2.0437184	7/4/11 10:54
84	0.6791288	1.9912928	0.857132	1.9263704	7/5/11 11:42
85	0.6654128	2.0446328	0.7882472	1.7907344	7/6/11 12:30
86	0.6687656	2.0897432	0.7172288	1.6871024	7/7/11 13:18
87	0.7806272	2.1564944	0.7251536	1.6959416	7/8/11 14:18

	LW	HW	LW	HW	date
88	0.922664	2.1979472	0.7342976	1.7084384	7/9/11 15:06
89	1.0174568	2.2369616	0.7434416	1.7370896	7/10/11 15:54
90	1.0467176	2.2451912	0.7452704	1.791344	7/11/11 16:42
91	1.0589096	2.2643936	0.7562432	1.84316	7/12/11 17:30
92	1.0083128	2.2476296	0.7501472	1.8407216	7/13/11 18:18
93	0.98972	2.207396	0.73064	1.8474272	7/14/11 19:18
94	0.899804	2.1522272	0.7193624	1.8648008	7/15/11 20:06
95	0.8687144	2.083952	0.698636	1.8733352	7/16/11 20:54
96	0.8583512	1.9882448	0.6699848	1.8965	7/17/11 21:42
97	0.8187272	1.8498656	0.6660224	1.8611432	7/18/11 22:30
98	0.8080592	1.6791776	0.6644984	1.8754688	7/19/11 23:18
99	0.8287856	1.56122	0.687968	1.9324664	7/21/11 0:18
100	0.835796	1.5267776	0.9007184	1.9519736	7/22/11 1:06
101	0.7154	1.4633792	1.0073984	1.9806248	7/23/11 1:54
102	0.6745568	1.4746568	1.0790264	1.9906832	7/24/11 2:42
103	0.674252	1.5234248	1.1079824	2.0324408	7/25/11 3:30
104	0.675776	1.6133408	1.0686632	2.0857808	7/26/11 4:18
105	0.6968072	1.6874072	1.094876	2.14034	7/27/11 5:18
106	0.7141808	1.763912	1.0561664	2.2013	7/28/11 6:06
107	0.7227152	1.8245672	0.9772232	2.2168448	7/29/11 6:54
108	0.7266776	1.8608384	0.8781632	2.1881936	7/30/11 7:42
109	0.724544	1.901072	0.8101928	2.1269288	7/31/11 8:30
110	0.713876	1.9166168	0.7172288	2.0446328	8/1/11 9:18
111	0.6904064	1.9656896	0.6928448	1.9568504	8/2/11 10:18
112	0.6745568	2.0239064	0.6891872	1.8358448	8/3/11 11:06
113	0.6748616	2.0333552	0.6861392	1.6529648	8/4/11 11:54
114	0.6754712	2.0495096	0.6992456	1.5974912	8/5/11 12:42
115	0.7592912	2.0738936	0.712352	1.581032	8/6/11 13:30
116	0.8949272	2.0726744	0.7141808	1.59932	8/7/11 14:18
117	0.947048	2.082428	0.719972	1.663328	8/8/11 15:18
118	0.9625928	2.1141272	0.7339928	1.7437952	8/9/11 16:06
119	0.9878912	2.1421688	0.742832	1.7812856	8/10/11 16:54
120	0.9010232	2.1183944	0.733688	1.791344	8/11/11 17:42
121	0.8138504	2.0888288	0.7239344	1.823348	8/12/11 18:30
122	0.79922	2.0482904	0.7035128	1.8367592	8/13/11 19:18
123	0.724544	1.9809296	0.6840056	1.84316	8/14/11 20:18
124	0.724544	1.8876608	0.6766904	1.8526088	8/15/11 21:06
125	0.6998552	1.7861624	0.6769952	1.8526088	8/16/11 21:54
126	0.6837008	1.6682048	0.6806528	1.8876608	8/17/11 22:42
127	0.6840056	1.5898712	0.7583768	1.920884	8/18/11 23:30
128	0.6876632	1.5069656	0.8629232	1.9260656	8/20/11 0:18
129	0.686444	1.4261936	0.9976448	1.8715064	8/21/11 1:18
130	0.6858344	1.422536	1.1003624	1.8693728	8/22/11 2:06
131	0.6855296	1.4871536	1.0799408	1.9510592	8/23/11 2:54

	LW	HW	LW	HW	date
132	0.6852248	1.5920048	1.0583	2.0135432	8/24/11 3:42
133	0.691016	1.6813112	0.950096	2.0598728	8/25/11 4:30
134	0.7013792	1.7407472	0.8406728	2.0876096	8/26/11 5:18
135	0.7221056	1.7925632	0.724544	2.0818184	8/27/11 6:18
136	0.7160096	1.8513896	0.6958928	2.0754176	8/28/11 7:06
137	0.7172288	1.9394768	0.6977216	2.0345744	8/29/11 7:54
138	0.7044272	2.0053136	0.7010744	1.9736144	8/30/11 8:42
139	0.6974168	2.077856	0.727592	1.9129592	8/31/11 9:30
140	0.7010744	2.0940104	0.7312496	1.7843336	9/1/11 10:18
141	0.7056464	2.1025448	0.7324688	1.738004	9/2/11 11:18
142	0.8290904	2.1116888	0.73826	1.6718624	9/3/11 12:06
143	0.9369896	2.0735888	0.7288112	1.6499168	9/4/11 12:54
144	0.9991688	2.0239064	0.7050368	1.6352864	9/5/11 13:42
145	0.9403424	1.9800152	0.6995504	1.663328	9/6/11 14:30
146	0.8345768	1.9684328	0.6995504	1.7276408	9/7/11 15:18
147	0.8153744	2.0037896	0.7022936	1.8093272	9/8/11 16:18
148	0.7830656	2.0193344	0.7074752	1.9083872	9/9/11 17:06
149	0.7955624	2.0043992	0.70778	1.899548	9/10/11 17:54

APPENDIX D: DAILY PEAKS ABOVE CULVERTS

Appendix D: ABOVE CULVERT PEAKS

	LW	HW	LW	HW	date
1	1.29613	1.47444	1.29095	1.67957	4/10/11 14:30
2	1.28302	1.53967	1.27967	1.70395	4/11/11 15:18
3	1.27297	1.70426	1.26961	1.76461	4/12/11 16:18
4	1.26413	1.74602	1.26230	1.68597	4/13/11 17:06
5	1.25376	1.85788	1.25407	1.78594	4/14/11 17:54
6	1.24431	1.99839	1.26626	1.86306	4/15/11 18:42
7	1.24736	2.11391	1.30924	1.91366	4/16/11 19:30
8	1.25834	2.17091	1.32600	1.90055	4/17/11 20:18
9	1.26596	2.20230	1.32966	1.86519	4/18/11 21:18
10	1.26961	2.21327	1.33515	1.88409	4/19/11 22:06
11	1.27510	2.20108	1.32753	1.75973	4/20/11 22:54
12	1.27175	2.03588	1.27845	1.73139	4/21/11 23:42
13	1.25681	1.92585	1.24431	1.72773	4/23/11 0:30
14	1.23913	1.82923	1.23121	1.71736	4/24/11 1:18
15	1.22999	1.68231	1.22420	1.67469	4/25/11 2:18
16	1.22328	1.49852	1.22237	1.62897	4/26/11 3:06
17	1.22206	1.46804	1.21993	1.67347	4/27/11 3:54
18	1.22145	1.51742	1.21871	1.72437	4/28/11 4:42
19	1.22298	1.40738	1.21871	1.60306	4/29/11 5:30
20	1.21963	1.44000	1.21566	1.78015	4/30/11 6:18
21	1.17726	1.52534	1.21871	1.86641	5/1/11 7:18
22	1.22328	1.58630	1.22024	1.91792	5/2/11 8:06
23	1.22359	1.61830	1.21993	1.97309	5/3/11 8:54
24	1.22664	1.65427	1.22206	1.98254	5/4/11 9:42
25	1.22938	1.66951	1.22420	1.99473	5/5/11 10:30
26	1.22999	1.70792	1.22664	2.00327	5/6/11 11:18
27	1.23426	1.73870	1.23212	1.99534	5/7/11 12:18
28	1.23426	1.73596	1.23090	1.79387	5/8/11 13:06
29	1.22481	1.68140	1.22511	1.69725	5/9/11 13:54
30	1.22206	1.75851	1.22633	1.69542	5/10/11 14:42
31	1.22145	1.85696	1.22725	1.64726	5/11/11 15:30
32	1.22206	1.91061	1.23151	1.65762	5/12/11 16:18
33	1.22481	2.05783	1.28302	1.78015	5/13/11 17:18
34	1.24371	2.18401	1.34490	1.86428	5/14/11 18:06
35	1.25955	2.18310	1.33850	1.85087	5/15/11 18:54
36	1.29491	2.28612	1.37294	1.95511	5/16/11 19:42
37	1.29430	2.33093	1.38513	1.88744	5/17/11 20:30
38	1.29186	2.21846	1.35221	1.85239	5/18/11 21:18
39	1.27479	2.12366	1.31686	1.81002	5/19/11 22:18
40	1.26413	2.03375	1.28211	1.81551	5/20/11 23:06
41	1.25773	1.90939	1.24218	1.81246	5/21/11 23:54
42	1.24127	1.73382	1.23487	1.71615	5/23/11 0:42
43	1.23487	1.50461	1.23060	1.71615	5/24/11 1:30

	LW	HW	LW	HW	date
44	1.23365	1.45493	1.23182	1.72986	5/25/11 2:18
45	1.23456	1.37142	1.23029	1.78320	5/26/11 3:18
46	1.23517	1.42902	1.22907	1.84904	5/27/11 4:06
47	1.23609	1.50096	1.23212	1.93408	5/28/11 4:54
48	1.23944	1.53967	1.23365	1.94078	5/29/11 5:42
49	1.23913	1.58691	1.23517	2.00540	5/30/11 6:30
50	1.25133	1.65153	1.24431	2.04381	5/31/11 7:18
51	1.28821	1.69115	1.25955	2.04167	6/1/11 8:18
52	1.27754	1.64848	1.25834	2.02978	6/2/11 9:06
53	1.28089	1.69115	1.26443	2.02857	6/3/11 9:54
54	1.30406	1.78686	1.27144	2.02247	6/4/11 10:42
55	1.29247	1.77101	1.27358	1.98650	6/5/11 11:30
56	1.27053	1.77680	1.26016	1.81703	6/6/11 12:18
57	1.24157	1.87220	1.24614	1.72620	6/7/11 13:18
58	1.23456	1.93072	1.24523	1.62958	6/8/11 14:06
59	1.23243	1.98345	1.25620	1.59026	6/9/11 14:54
60	1.23548	2.05295	1.27114	1.62928	6/10/11 15:42
61	1.21048	2.13738	1.31259	1.70822	6/11/11 16:30
62	1.21963	2.18005	1.32173	1.73657	6/12/11 17:18
63	1.22145	2.19499	1.31991	1.75242	6/13/11 18:18
64	1.22237	2.21602	1.33027	1.80880	6/14/11 19:06
65	1.22968	2.23491	1.34124	1.88622	6/15/11 19:54
66	1.23974	2.22455	1.33667	1.92890	6/16/11 20:42
67	1.24005	2.15109	1.30253	1.91762	6/17/11 21:30
68	1.23029	2.06545	1.25955	1.87556	6/18/11 22:18
69	1.21688	1.91884	1.19799	1.88561	6/19/11 23:18
70	1.20286	1.75882	1.19189	1.89659	6/21/11 0:06
71	1.19738	1.63233	1.18976	1.91640	6/22/11 0:54
72	1.19768	1.48236	1.19280	1.87647	6/23/11 1:42
73	1.19646	1.38452	1.18793	1.89720	6/24/11 2:30
74	1.19311	1.42079	1.18945	1.94139	6/25/11 3:18
75	1.19768	1.48419	1.19158	1.96852	6/26/11 4:18
76	1.19951	1.59819	1.19402	2.05661	6/27/11 5:06
77	1.24005	1.69877	1.24005	2.11117	6/28/11 5:54
78	1.26474	1.69877	1.21871	2.10385	6/29/11 6:42
79	1.25529	1.71096	1.21048	2.11178	6/30/11 7:30
80	1.25407	1.75425	1.20896	2.14317	7/1/11 8:18
81	1.26413	1.83532	1.21292	2.13768	7/2/11 9:18
82	1.26199	1.88074	1.21566	2.07581	7/3/11 10:06
83	1.24828	1.91152	1.21201	2.00357	7/4/11 10:54
84	1.21353	1.95480	1.20804	1.88622	7/5/11 11:42
85	1.18854	2.00601	1.22999	1.74967	7/6/11 12:30
86	1.19250	2.04990	1.26382	1.64574	7/7/11 13:18
87	1.19859	2.11421	1.29369	1.65336	7/8/11 14:18

	LW	HW	LW	HW	date
88	1.21201	2.15292	1.30954	1.66677	7/9/11 15:06
89	1.21414	2.18950	1.32265	1.69420	7/10/11 15:54
90	1.21871	2.19803	1.33027	1.75028	7/11/11 16:42
91	1.22237	2.21754	1.34185	1.80240	7/12/11 17:30
92	1.23334	2.20139	1.33606	1.80118	7/13/11 18:18
93	1.22907	2.16237	1.31107	1.80911	7/14/11 19:18
94	1.22359	2.10842	1.29156	1.82618	7/15/11 20:06
95	1.21871	2.04228	1.25620	1.83532	7/16/11 20:54
96	1.21079	1.94779	1.19616	1.85971	7/17/11 21:42
97	1.19219	1.81033	1.18427	1.82587	7/18/11 22:30
98	1.18671	1.63934	1.17787	1.84020	7/19/11 23:18
99	1.18549	1.52229	1.17391	1.89628	7/21/11 0:18
100	1.18671	1.48785	1.17634	1.91335	7/22/11 1:06
101	1.18488	1.42262	1.17299	1.94109	7/23/11 1:54
102	1.17939	1.43390	1.17269	1.95023	7/24/11 2:42
103	1.17756	1.48236	1.17726	1.99077	7/25/11 3:30
104	1.18854	1.57289	1.17391	2.04411	7/26/11 4:18
105	1.22755	1.64787	1.17726	2.09775	7/27/11 5:18
106	1.25041	1.72407	1.20408	2.15750	7/28/11 6:06
107	1.26535	1.78747	1.20621	2.17213	7/29/11 6:54
108	1.26961	1.82100	1.20225	2.14347	7/30/11 7:42
109	1.26596	1.86153	1.20317	2.08465	7/31/11 8:30
110	1.24950	1.87769	1.19433	2.00296	8/1/11 9:18
111	1.20743	1.92768	1.17909	1.91487	8/2/11 10:18
112	1.17177	1.98528	1.19067	1.79539	8/3/11 11:06
113	1.17177	1.99504	1.20561	1.61282	8/4/11 11:54
114	1.17238	2.01028	1.23029	1.55552	8/5/11 12:42
115	1.17543	2.03314	1.24950	1.53936	8/6/11 13:30
116	1.17939	2.03070	1.25133	1.55856	8/7/11 14:18
117	1.17756	2.03954	1.25834	1.62440	8/8/11 15:18
118	1.17665	2.07246	1.28089	1.70517	8/9/11 16:06
119	1.18366	2.10019	1.29552	1.73992	8/10/11 16:54
120	1.19158	2.07581	1.28424	1.75120	8/11/11 17:42
121	1.19097	2.04716	1.26565	1.78686	8/12/11 18:30
122	1.18305	2.00784	1.22999	1.79966	8/13/11 19:18
123	1.17665	1.94139	1.17452	1.80271	8/14/11 20:18
124	1.16964	1.84690	1.17086	1.81368	8/15/11 21:06
125	1.16872	1.74510	1.16933	1.81368	8/16/11 21:54
126	1.16842	1.62806	1.16751	1.84843	8/17/11 22:42
127	1.16811	1.54668	1.16751	1.88165	8/18/11 23:30
128	1.16872	1.46499	1.16842	1.88592	8/20/11 0:18
129	1.16872	1.38544	1.16781	1.82923	8/21/11 1:18
130	1.16811	1.38117	1.16811	1.82557	8/22/11 2:06
131	1.16751	1.44579	1.16872	1.90878	8/23/11 2:54

	LW	HW	LW	HW	date
132	1.16903	1.55795	1.16994	1.97766	8/24/11 3:42
133	1.17939	1.64574	1.17452	2.02308	8/25/11 4:30
134	1.19677	1.70426	1.17482	2.04990	8/26/11 5:18
135	1.22938	1.75821	1.18396	2.04350	8/27/11 6:18
136	1.23182	1.81490	1.18488	2.03771	8/28/11 7:06
137	1.23273	1.90421	1.18793	1.99473	8/29/11 7:54
138	1.20042	1.96943	1.19158	1.93499	8/30/11 8:42
139	1.17909	2.04076	1.25529	1.87403	8/31/11 9:30
140	1.19463	2.05508	1.26199	1.74632	9/1/11 10:18
141	1.18518	2.06453	1.26230	1.70334	9/2/11 11:18
142	1.19037	2.07368	1.27083	1.63446	9/3/11 12:06
143	1.19219	2.03466	1.24919	1.61129	9/4/11 12:54
144	1.18610	1.98285	1.20103	1.60215	9/5/11 13:42
145	1.17543	1.94017	1.17970	1.62653	9/6/11 14:30
146	1.17391	1.93377	1.17726	1.69146	9/7/11 15:18
147	1.17360	1.96943	1.18305	1.77345	9/8/11 16:18
148	1.17452	1.98224	1.19219	1.87525	9/9/11 17:06
149	1.17756	1.97218	1.18854	1.86794	9/10/11 17:54

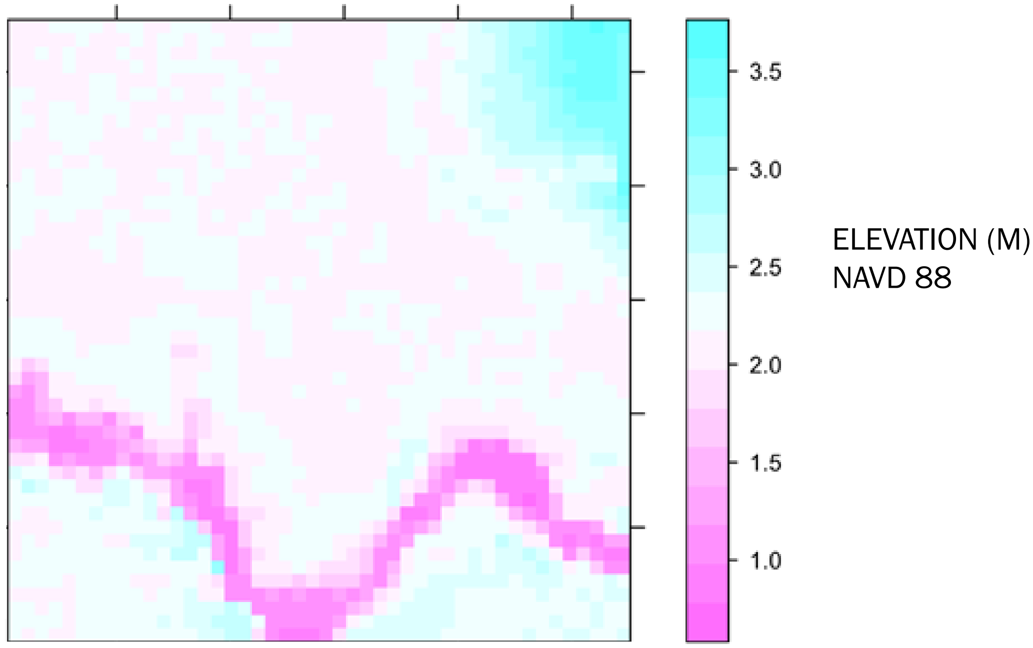
APPENDIX E: WATER SURFACE ELEVATION MODEL METHODS

APPENDIX E: WATER SURFACE ELEVATION MODEL METHODS

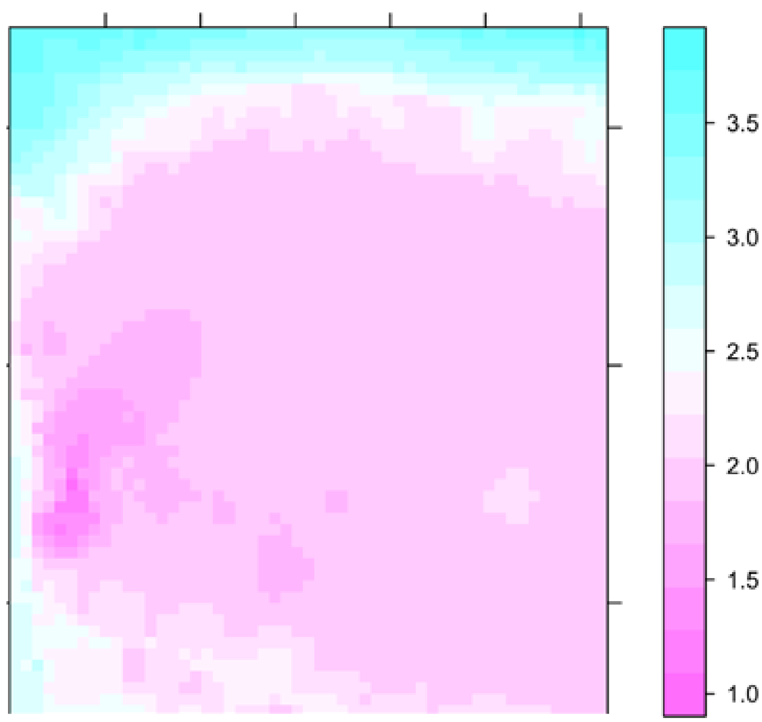
I developed a water elevation surface model in GIS using a topographic surface model and the high and low values for each of the four tidal water elevations. To do this, I created a ground surface digital elevation model (DEM) of lower Spring Branch Creek Watershed, using 2007 DWR LiDAR bear earth xyz files and RTK GPS ground surveys conducted in 2009. There were several steps necessary to create this surface model.

First, I tested the LiDAR accuracy. I brought the two XYZ file sources (point files that have three dimensional coordinates) into ArcScene in order to see whether the ground survey XYZ and LiDAR XYZ differed from one another. I found up to a half a meter difference in elevations between ground survey and LiDAR in areas within the marsh and lower Spring Branch Creek. Of particular error were areas with taller vegetation such as cattails and bull rush indicating that the LiDAR bare earth model may actually be a model of vegetation surface (not ground). In the upland habitats (grasslands) LiDAR appears to be hitting the actual ground surface, as there was no detectable difference between the two. Because of the inaccuracy of LiDAR observed within the marsh, I only used RTK data locations to assess differences in water elevations above and below the culverts Marsh areas that were not part of RTK ground survey are indicated on Figure 7. In addition, in order to ensure accuracy of the hypsometric diagram, I created two new DEMs derived only from ground survey xyz points (DEMs shown below).

To produce a DEM for the entire lower Spring Branch Creek cooridor, I digitized two clipping boundaries (1) of the Spring Branch Creek watershed and (2) boundary shapefile for the ground survey location. Then, I appended the two boundary files, selected only the Spring Branch Creek boundary and exported that as a new shapefile. This new shapefile had a “donut hole” where the ground survey data exists. Next, I clipped the ground survey XYZ points to ground survey boundary, and the LiDAR XYZ data to the Spring Branch Creek donut hole boundary. After appending the two xyz files, I created an Inverse Distance Weight (IDW) interpolated surface model using 3D analyst tools. Lastly, I reclassified the IDW raster to display the range of high and low tidal elevations.



DIGITAL ELEVATION MODEL USED IN HIPSOMETRIC DIAGRAM : BELOW CULVERTS



DIGITAL ELEVATION MODEL USED IN HIPSOMETRIC DIAGRAM : ABOVE CULVERTS

APPENDIX F: REFERENCE SITE COMPARISON PHOTOS

BENICIA STATE RECREATION AREA
Notes: Soft bird's beak occurs in a much wider band when compared to the Spring Branch Creek population.

RUSH RANCH
Notes: Soft bird's beak at Spring Branch Creek occupies a much narrower range than the Benecia population.

BENICIA STATE RECREATION AREA
Notes: Soft bird's beak appears to be a more robust population, larger in stature when compared to the Spring Branch Creek population. Photo taken by Jessie Olson on November 25th.

RUSH RANCH
Notes: Soft bird's beak at Spring Branch Creek is less robust and smaller in stature than the Benecia population. Photo taken by Jessie Olson on November 25th.