Title

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Post-project evaluation of Tule Ponds in Fremont, California: Integration of stormwater treatment and wetland restoration

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by

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Abstract

Stormwater can contaminate water supplies and cause biological impacts to streams, estuaries, and coastal zones due to excess sediment, nutrients, pesticides, or heavy metals. Best management practices (BMPs) for stormwater control are implemented with greater frequency now that municipalities are required to have a National Pollutant Discharge Elimination System (NPDES) permit according to Clean Water Act revisions. After BMP construction, however, engineers and hydrologists rarely conduct follow-up assessments or evaluations. For this project, we evaluated the effectiveness of the Tule Ponds in Fremont, a constructed permanent wetland designed to simultaneously treat urban runoff and provide wildlife habitat. Using survey measurements of the pond dimensions and elevations, wildlife observations, and conversations with the site manager, we analyzed the success of the original wetland design. While our findings indicate the ponds did not function exactly as intended, they still succeeded in reaching overall intended objectives. The ponds catch, retain, and treat stormwater; however, the banks were unstable and have eroded, and the system dries out almost every summer due to infiltration into the ground. Based on current BMP guidelines, the ponds are too deep in winter, their banks are too steep, and emergent vegetation is insufficient. These factors may limit the ability of the wetland to support aquatic wildlife, and may limit contaminant removal. In addition, excess pond depth and algal growth result in low oxygen levels. Still, the site is populated with common birds (Canada geese, mallards and egrets), amphibians (bullfrogs and Pacific treefrogs), and insects (dragonflies and damselflies). We examine trade-offs between multiple use aims of this wetland system. In addition, because the site is only accessible through scheduled classroom field trips and is not generally open to the public, Tule Ponds may represent a missed opportunity for broader public education about urban ecology and stormwater management.

INDRODUCTION

Stormwater runoff is an important environmental issue in urban areas. Much of the precipitation reaching the ground cannot infiltrate impervious surfaces such as roofs, asphalt, and cement, and thus becomes runoff. This runoff accumulates toxins from cars (e.g., zinc and chromium), pesticides from lawns and roadside treatments (e.g., glyphosate and pyrethroids), and nutrients from lawn fertilizers (i.e., nitrogen and phosphorous). In the recent past, these constituents were typically ushered directly to streams and creeks via underground stormwater pipes. These toxins have significant impacts on aquatic ecology and can result in species decline and loss of biodiversity (Walsh, 2000; Brown et al., 2005). For additional information on stormwater pollution and applicable regulations, refer to Appendix A.

With these concerns in mind, we identified and evaluated the Tule Ponds, an artificial stormwater wetland recently constructed in Fremont with the dual purpose of stormwater treatment and aquatic habitat restoration. This site was unique in that it provided the opportunity to examine how one wetland area can simultaneously fulfill two different and sometimes conflicting objectives. In this paper, we describe our effort to evaluate the current conditions, and thus functionality, of a constructed wetland in a brief survey that would be feasible for county officials or land managers to replicate. With agency budget cuts and staffing shortages, there is a need for rapid, low-cost, and accurate evaluation criteria so that agency personnel can determine the success of a stormwater pond best management practice (BMP). This analysis can form the basis for such a survey technique.

In sum, we intended to: 1) compare current wetland dimensions to dimensions shown on engineering plans; 2) compare current wetland dimensions to BMP guidelines; 3) evaluate water quality; 4) examine trade-offs related to multiple use constructed wetlands; and 5) recommend techniques for a rapid assessment approach.

Tule Ponds: Site, History, and Structure

Site Location. The Tule Ponds Project is a constructed wetland on a 14-acre site in Fremont, California (Figure 1) that receives an average annual rainfall of 13.8 inches. Tule Ponds is located in upper areas of the Mowry Slough watershed, which is largely urbanized and comprises approximately 1,750 acres. The Tule Ponds drain and treat stormwater from approximately 280 acres of residential land use via one main stormwater line (Woodward Clyde, 1999; Figure 2). The wetlands are surrounded by residential land use on two sides, a road on the third, and Tyson Lagoon on the fourth side. Tyson Lagoon drains other parts of the watershed as well, including the Fremont Bay Area Rapid Transit (BART) parking lot. Tyson Lagoon is a natural wetland 100 meters (m) wide, 300 m long, and about 2 m deep, and drains an estimated 400 acres of urban land.

History. The site was modified by Alameda County in the 1950s to perform flood control for the outlying urban area. Additional stormwater features were constructed in the 1970s, prior to development of the Fremont BART station. The area now occupied by the constructed wetlands was used informally as an all terrain vehicle site, contained few native plants, and possessed little wildlife value. The Tule Ponds were conceptualized and designed by Richard Wetzig, a retired ecological engineer from the Alameda County Public Works Agency, after working with another stormwater system in Fremont: the Demonstration Urban Stormwater Treatment (DUST) Marsh Basin. Tule Ponds construction was funded by the Public Works Agency and was not part of any specific development mitigation project.

Structure and Function. The site includes three distinct ponds (from north to south: Ponds A, B, and C), a peripheral walking trail, and three bridges. A small building used for management, administration, and education is located at the southern end (Figure 3). The site, which is managed as a youth education center and is not open to the public, is surrounded by a fence.

As described above, one of the key functions of Tule Ponds is to treat stormwater from surrounding urbanized areas. As engineered, stormwater was to enter the constructed wetlands via a pipe at the northern end of Pond A and flow south. Pond A is designed to slow water flow, allowing a majority of suspended sediment to drop out of the water. Ponds B and C provide additional treatment to the water with islands intended to slow high flows and encourage water circulation. From Pond C, the runoff enters Tyson Lagoon and then, via a flood control channel, Mowry Slough and out to South San Francisco Bay. Two additional culverts allow urban stormwater to enter in the middle of Pond A and in between Ponds B and C. There is one island in Pond B and two islands in Pond C, which were designed to create safe nesting habitat for birds. A ledge was also constructed in Ponds A and B to allow for vegetation growth and for safety reasons (to prevent people from inadvertently falling into the ponds or to provide a safe place to stand if they did fall).

METHODS

We spent a total of three days at the site, characterizing the physical features of the wetlands and comparing these to the original design, discussing the functioning and management of the wetland with the manager, and observing the system and its ecology first hand. Based on surveys of previous evaluation studies on the Internet and in the literature, we developed a set of criteria regarding the efficacy of the wetland (Table 1). As part of our study we reviewed the 1997 Tule Ponds engineering plans, and the Tule Pond Baseline Characterization report prepared by Woodward-Clyde in 1999. To date, the project has not been surveyed since construction, thus no "as-built" drawings were available.

<u>Spatial Survey.</u> We compared the 1997 Alameda County engineering plans for the site to the current form. Because no "as-built" plans were available, discrepancies between current conditions and the plans could be associated with deviations from the plans during the construction period or hydrologic processes (e.g., erosion and deposition). In this report, however, we focus on the latter possible cause. Further, the site has not been dredged or significantly altered since construction, so post construction activities would not have altered the current structure. We surveyed five cross sections perpendicular to stormwater flow: one cross section for each of the three ponds and one for

each of the two small inlets connecting the ponds, as seen in Figure 3. From these cross sections, we calculated bank slopes, bed elevation, water surface elevation, as well as the location and slope of a two meter (m) safety ledge (only present in Pond A and B). Pond depth was measured from a boat since the ponds were too deep to wade across. Slopes were calculated according to the engineering plans. Thus a horizontal to vertical slope of two feet (ft) to one foot was represented by a 2 : 1 ratio.

We also measured prominent features of the site related to the function of the wetland and habitat for wildlife, including the elevations of two pedestrian bridge crossings, the pond bed at various locations off the cross section, at observable high water marks, and along the three constructed islands. We also profiled the pipe outflow to determine if this area was incising due to erosional forces or aggrading due to sedimentation. We estimate an error of ± 0.2 ft in the z direction and ± 0.3 ft in the x, y plane with the survey tools used in this study. Therefore, slopes are considered significantly different if they increase by more than a ratio of 0.38 : 1 for 2:1 slopes or 0.31 : 1 for 1.5 : 1 slopes. Elevation is considered significantly different if more than 0.2 ft of difference is recorded.

Water Chemistry. We sampled basic water chemistry at the site using two YSI hand probes (YSI 30 and YSI 55) to measure conductivity in micro Siemens per centimeter (uS/cm), salinity in parts per thousand (ppt), temperature (^{o}C), and dissolved oxygen in milligrams per liter (mg/L). On April 7, 2006 we sampled at six inches (in) below water surface at two locations in each pond. On April 14, 2006 we sampled from the boat in the center of the pond at one and eight ft below water surface. Locations for water samples are noted as "W_x" in Figure 3.

Vegetation surveys. The ponds support a basic fauna of tule reeds, hydrophyte plant composition, willows, coyote scrub, and grasses. We recorded the elevation ranges of these plants to describe the physical flora ranges at the site. We estimated percent cover of pond surface area with emergent vegetation through site observations.

Wildlife observations. We documented wildlife encountered while at the site and supplemented our observations with information from the site manager.

Interview of site manager. Joyce Blueford, a former geologist and current manager of Tule Ponds through the nonprofit education organization Math and Science Nucleus, has been involved with Tule Ponds for several years. She offered a wealth of information on the functioning of the ponds during the three site visits.

Hydrologic design. We determined catchment size (drainage area) for the Tule Ponds by two methods. We used the area for the one main stormwater pipe (line E) stated in a Woodward-Clyde report (1999) and also calculated the approximate watershed area using the Alameda County streams and rivers map. Both values indicated the drainage area was 280 acres (ac). Based on the catchment size, we used California BMP guidelines to determine the pond size required to treat the volume of rainfall based on a 0.6 inch storm according to the Equation 1 (SWQTF, 1993).

Equation 1. *required pond volume in feet*^{3} *= 3 * (storm depth in inches) * (impervious area (0.9 of the watershed) in acres) * 43560 / 12*

We determined flow into the site by using the rational method (Equation 2).

Equation 2. *volume of runoff (Q) = cover factor (C) * rainfall intensity (I) * watershed area (A)*

Using field measurements, we calculated the volume and surface area for each pond and connecting inlet surface area; we calculated volume at the high water mark using basic geometry. Due to the complicated hydraulics at the site, we were unable to evaluate the amount of inflow, outflow, and hydraulic residence time. Rainfall data was from the CDEC web site (http://cdec.water.ca.gov).

RESULTS

Surveys

The surveys indicated a number of differences between the engineering plans and the current pond form or dimensions (Table 2).

Pond A. The bed level in Pond A was 1.7 feet higher than the design. The water surface level was also higher than the water level slated for the design, though this is a result of large precipitation events in March 2006. According to Blueford, the water level declines after the last rains due to infiltration. The cross section (Figure 4) indicates that three bank slopes were shallower than designed and one had the same slope. The west and east safety ledges (or benches) were 1.5 ft and 2.0 ft shorter than the original 6.6 ft planned bench, and both sloped inwards. The long profile shows a slope of 2.7 : 1, and was initially designed to be 1.5 : 1 (Figure 5). Pond A had a distinctly soft layer of sediment that the survey rod sank into without any pressure. This extremely soft layer ranged from two to six inches thick and is likely a combination of sediment and decaying plant material.

Pond B. The bed level of pond B was 1.4 ft higher than the design. The cross sections (Figure 6) indicate that all four bank slopes and both island slopes were shallower than designed (Table 2). The width of the ledge was 0.6 and 2.6 ft shorter than planned. The island elevation was, on average, equal to the water surface elevation of 48.1 ft, about 0.36 ft higher than the plans.

Pond C. The bed level in Pond C was 0.21 ft lower than designed. The cross sections (Figure 7) indicate that the two bank slopes were similar to the plan and the two island banks were shallower. The island elevation was nearly identical to the level in the plans (Table 2). Pond C does not have a ledge.

Inlets and bridges. The inlets in between the ponds were designed to contain a 2 : 1 slope and a depth of about 6.6 ft. Cross sections of the inlets show the slopes were either the same, or in one case, steeper than designed (Figures 8 and 9). Bridges 1 and 2 were 0.44 and 0.07 ft higher than in the plans, respectively.

Hydrology

The hydrology of the site was much more complex than we initially estimated. According to our calculations and a Woodward-Clyde report (1999), the drainage area of the wetland was about 280 acres (ac). Following the very general one percent rule (BASMAA, 1999), a drainage area of that size requires a wetland with a surface area of approximately three acres. At the time of sampling, the surface area of the entire wetland was 70,300 ft^2 (1.61 ac), and was 65,900 ft^2 (1.51 ac) at the planned water surface elevation, about half of the recommended size.

The volume of runoff entering the ponds in a 0.6-inch storm is 609,000 ft^3, assuming a runoff coefficient of 0.9. The wetland capacity is about 180,000 ft^3 (Table 3) at the standard water surface elevation, only 11% of the recommended size of 1,646,000 ft^3 (SWQTF, 1993). This recommended size is based on a report produced by the Federal Highway Administration, and assumes that the greater the wetland capacity in relation to the incoming volume of runoff, the more total suspended solids will be removed (SWQTF, 1993). At the current dimensions, the method predicted 11% removal of total suspended solids. The current high water mark, at an elevation of 49.39 ft, corresponded to an approximate volume of 323,800 ft^3 of water stored in the wetland. According to Blueford, some additional water enters the wetland at Pond C due to inflows from both Tyson Lagoon and the South Tule Pond (Figure 2). Also, well water enters Tyson Lagoon and overflows into Tule Ponds when the Alameda City Water District Peralta Wells are in use.

The site was designed to have four inflow areas, but only three were observed. As noted above, no as-built plans were available for us to verify that that all inflow areas were constructed. Neither the general flow predictions or design of the outflow area were available to us, so we relied on interviews with Blueford to answer questions about the hydraulics of the site. The majority of the inflow enters through the pipe and travels from Pond A to C according to design. However, during intense rainstorms, the water level in Tyson Lagoon rises above that of Tule Ponds, thus water from Tule South and Tyson Lagoon flows into Pond C. A two-foot earthen dam designed to prevent such a backflow was demolished during the first major storm event after construction. As a result, Tyson Lagoon and Tule Ponds are now connected via surface water for a majority of the rainy season. Furthermore, the outflow device that was intended to carry water out of Pond C and into Tyson

Lagoon silted up after construction and was removed. Blueford reported that the ponds tend to dry out late in the summer due to impervious soils and groundwater infiltration.

Water chemistry

Water chemistry readings from two site visits are listed in Table 4 and Figure 10. Average dissolved oxygen levels were much lower at depths of eight feet compared to one foot. Conductivity was similar across a pond and at different depths but differed between Pond C and Ponds A and B. Only 1.0 ppt of salinity was detected in Pond C, the outlet, and Tyson Lagoon.

Vegetation coverage

At present water level, roughly 10% of the surface area of the pond was covered with some type of emergent vegetation. At the designed water surface elevation, surface area covered by vegetation would be close to 5%, since the areas nearby Bridges 1 and 2 on the west side would no longer be inundated. Blueford reported undertaking an extensive tule propagation and restoration program, because these native plants are thought to biofilter pollutants from stormwater better than cattails. It is of note that on April 14, 2006 we observed an algal bloom developing on the surface of Pond C that covered approximately one to two percent of the pond and was absent on April 7.

There were three main groupings of vegetation at levels below the observable high water mark: tule reeds, an assortment of hydrophytes, and willows/coyote brush that were stratified by elevation (see photos). The tule ranged from 0.4 to three feet below water level, hydrophytic emergent vegetation ranged from two to six inches below water level, and coyote brush and willow ranged from one inch below current water level and above.

Wildlife

We observed a variety of bird and amphibian species at the site. In particular, Pacific treefrog (*Hyla regilla*) tadpoles were abundant at the site and generally found in shallow inundated areas by bridges. Refer to Appendix B for additional information about observed wildlife.

Discussion

Pond dimensions and design

Overall the ponds' current structure was similar to the proposed design, yet there were some key differences between the engineering plans and observed conditions. We note again that such condition discrepancies could be a result of deviations from the original construction plan or result since construction due to hydrologic processes. However, since no as-built survey was conducted, we assume the project was built to design. Further, the current dimensions differed from guidelines stated in stormwater BMP handbooks for California (SWQTF, 1993) and the San Francisco Bay Area (BASMAA, 1999).

Bed aggradation. The beds of Ponds A and B were significantly higher than designed, which is likely due to a combination of sediment inputs from stormwater and sloughing of the banks.

Slope instability. The slopes of Ponds A and B were consistently shallower than designed. The most likely cause of this trend is erosion of the safety ledge and upper banks due to the instability of soils at their respective 1.5 : 1 or 2 : 1 ratio. Since this area is closed to the public and the land manager does not allow visitors to walk in the ponds, there has been minimal human disturbance to accelerate the hydrologic erosion process.

Current BMP guidelines recommend a bank slope of 4:1 or shallower for stormwater ponds to allow for sufficient vegetation and human safety (BASMAA, 1999). Synthesizing our vegetation surveys and elevation surveys, we observed a narrow band around each pond that could potentially support tule reeds; this area is only partially colonized at present. The presence of a three or four foot band of tule reeds around the majority of Pond A was not enough to prevent bank erosion from the upper banks or safety ledge.

Depth. BMP guidelines suggest that pond depth range between three and nine feet (SWQTF, 1993; BASMAA, 1999). Accordingly, Ponds A and B are too deep during the winter months; a temporary condition as the ponds typically dry out each summer. It is worth noting that the water level at the time of sampling was 1.4 ft higher than designed, due to sampling on the heels of an excessively wet season. However, the planned water depth of 9.8 ft for Ponds A and B would allow inadequate water mixing and, combined with accelerated eutrophication, could easily promote low oxygen levels (discussed in further detail below under water quality).

Pond capacity. The designed surface area and volume for water treatment were far below current recommendations. One must recognize that the pond already occupies a majority of available surface area and to build any deeper for additional space would have far exceeded the depth recommendations and required steeper slopes supporting less vegetation. The wetland is set in a larger basin that is about 10 ft deep, so the entire site could hold runoff much beyond that estimated on treatment capacity at the current water levels. The hydrology plans may have included some of this additional basin volume to accommodate typical or extreme storm events. We were unable to find any original sizing documents to confirm this supposition.

The high water mark (HWM) storage volume, based on two independent HWM observations were in line with a 0.35-inch storm over a 280-ac, 90% impervious urban watershed, but according to a near by rain gauge much larger storms have occurred this winter. In fact, the largest 24 hour storm was 2.38 inches which should have brought over 2,000,000 ft3 of runoff. The mismatch between the HWM and recent storm events could be due to a number of factors. First, significant portions of water from the wetland percolate into the aquifer during storm events due to greater pressure head. Second, it is possible that more rain infiltrates in the contributing drainage area than is reflected in the estimated 0.9 cover factor. Third, and most importantly, when water levels are high in Tule Pond they are also elevated in Tyson Lagoon; thus, the water has a short residence time in either system and quickly flows out of Tyson Lagoon's main outlet as new runoff enters from Tule Ponds.

Hydrology

The primary factor behind the reverse flow at Pond C is that the Tule Ponds were built on an aquifer recharge site. According to Blueford, the water surface elevation was intended to be higher in

Tule Ponds than in Tyson Lagoon, though there was no discussion of this in the planning designs. Tyson Lagoon is a sag pond, receives water from an aquifer below, and does not dry out like Tule Ponds. Thus water can flow from Tyson Lagoon into Tule Ponds during winter storms or during summer when water levels in the ponds drop due to recharge. We consider the infiltration at Tule Ponds to be the most significant deviation from the original design. The actual hydrology allows the site to treat more runoff than its capacity would predict because: 1) water does not outflow to Tyson as designed but mostly goes into groundwater; and 2) the site can process more water than calculated because percolation draws down the water level, the pond has a greater capacity to absorb the next storm, and some water from Tyson Lagoon is treated and enters the aquifer.

Due to extreme infiltration, perhaps up to 0.5 ft per day according to Blueford, all three ponds typically dry out in late summer, though in 2005 Pond A remained wet yearlong due to plentiful rainfall. Under dry summer conditions, wetland riparian and upland vegetation must be watered, and in fall the pond must be re-stocked with mosquitofish (*Gambusia affinis*) to control for mosquitoes. Typically, the insect populations in temporary waters differ from perennial systems since no larvae survive over the summer (Williams, 1997). Drying also excludes bullfrog tadpoles from surviving since they take two years to develop; a benefit as bullfrogs are invasive species and have caused declines in other frogs (Hayes and Jennings, 1986). From an ecological or restoration perspective, stormwater ponds in a Mediterranean climate that dry out every year may be preferred because most native species are adapted to aquatic systems with this characteristic. However, such wetlands are not able to treat as much water as permanent wetlands are, and may not be visually attractive to local residents during the dry season.

Water quality

The conductivity of Pond C was commensurate with the rest of Tule Ponds on April 7, 2006 but on April 14, 2006 Pond C had doubled its conductivity level, and algal mats had begun to grow on the water’s surface. Elevated conductivity and excessive algal growth are signs of nutrient pollution, too much nitrogen or phosphorous. This hypothesis was supported by Blueford, who reported that algae blooms were common in Pond C but not the other ponds and Pond C was the most nutrient rich of the three according to water chemistry tests.

Nutrient pollution and subsequent accelerated eutrophication can cause a decline in dissolved oxygen levels, and in extreme cases cause an entire pond, lake, or section of ocean to become anoxic, killing nearly all living organisms in the water. Even in early spring, we observed a strong reduction in dissolved oxygen at depth, a trend likely to worsen over late spring and summer with greater temperatures and sunlight. Recommended dissolved oxygen levels in aquatic habitats are above or equal to 7 mg/L, and levels ranging from 3-5 mg/L are dangerous for sensitive species (WQA, 1996). Below oxygen levels of 2 mg/L, the water is considered hypoxic and is detrimental to most wildlife. Low oxygen at depth was a strong trend in all three ponds. Historically, Pond C has been the most eutrophic pond, a condition that can exacerbate low oxygen levels in summer. Thus Pond C might not have to be as deep as Ponds A or B to have even lower oxygen levels. Nutrients are probably coming from Tule South or Tyson Lagoon, and seem to be trapped in Pond C even though the ponds were connected during sampling. Thus, it is important that Pond C be managed to pull out as much nitrogen and phosphate out of the water so it is not available for algae production (see management strategies below).

Wildlife

We determined that variations in island elevation were beneficial to the generally common wildlife species found on the site. Refer to Appendix B for additional detail.

Management strategies

<u>Structure</u>. We believe the Tule Ponds design would support more wildlife if constructed with a wide shelf extending out from the ponds at a 4:1 or shallower slope and a pond bottom that would hold the water so this area would be consistently inundated. While this design would remove some water treatment capacity, a shallower slope would allow for a greater proportion of the surface area

to have emergent vegetation, as recommended in the original plans. With a less pervious pond bottom, we expect the shelf would be inundated for much of the wet season. However, depending on the permeability of the pond bottom, we expect the shelf in Tule Ponds would be dry for much of the year. An increase in vegetation in the pond would allow for additional biofiltration and provide refuge, habitat, and food for aquatic wildlife, including insects, amphibians, fish, and birds (SWQTF, 1993). Proper vegetation is integral to providing the structure for wildlife and the processes of stormwater treatment. Further, a shallower wetland would diminish the low dissolved oxygen problem and enable fish or invertebrates to inhabit the benthos, leading to a more diverse invertebrate community. However, tule reeds and other vegetation provide habitat protection for mosquito larvae from mosquitofish. Thus, a trade-off exists between removing pollutants, providing habitat, and controlling vectors. Another factor to consider is that mosquitofish can impact native insect and amphibian populations (Lawler 1999), thus we recommend seeking a native fish alternative.

Nutrients**.** Management for excess nutrients, as indicated by algal blooms, could involve redesigning bank slopes so they are shallower and support more tule vegetation, raising the bed bottom to allow more mixing from surface winds so eutrophication does not contribute to hypoxia, and removing algal mats to prevent decomposition at the pond bed. Another structural modification would be a large earth barrier to block inflows from South Tule, as this seems to be the source of the nutrient-rich water, but this should be done with proper engineering, considering the original two-foot berm was quickly destroyed. Water mixing devices can be employed to prevent elevation gradients from forming, though these require electricity or fuel to provide power.

Designs for multiple uses

As mentioned above, it is challenging to optimize a wetland for removal of water pollutants and simultaneously provide suitable aquatic habitat. If we could modify the current design of the Tule Ponds to fulfill both objectives, the major inflow area would be shallower (4-6 ft deep) with more debris catchers, and would be cleaned often by hand to prevent wildlife from consuming debris.

Vegetation need not be as prevalent in Pond A as the goal in that pond is to remove sediment and allow for vehicles to remove the sediment occasionally. Ponds B and C should be much shallower (2-4 feet deep) to allow for more aquatic species that require a benthos with warmer temperatures, sunlight, and oxygen. The pond benthos would benefit from habitat heterogeneity, such as some rock structures or surface complexity that would provide refuge for fish from birds. However, at this site the major problem is water loss though the aquifer. Knowing this, we would not recommend this site as an ideal location for a permanent wetland, but rather a temporary wetland or extended detention pond.

Planning issues

Tule Ponds is one of the few restored wetlands in the Bay Area that is easily accessible by BART. In addition, the area is surrounded by medium-density residential neighborhoods that generate a high demand for public space. As such, Tule Ponds represent an important opportunity to educate the public about stormwater management, urban ecology, and wildlife. However, due to the high costs of liability insurance (estimated at $30-50,000 per year by Blueford) and the reluctance of the County or City to assume responsibility for the site, Tule Ponds are not regularly accessible to the public. Blueford attributed the high cost of liability insurance to the presence of a semi-permanent water body on the site and the lack of a full-time site supervisor, whereas public parks with full-time rangers are able to reduce the cost of their liability coverage.

Because the wetlands are home to birds and amphibians, opening the area to public use could pose human/wildlife conflicts. However, combining knowledge of how wildlife react to humans with careful planning and design (including fencing, marked trails, and signage), it is possible that such conflicts could be resolved. To exclude the public from a transit-oriented open space in the midst of a dense residential neighborhood seems like a missed opportunity for environmental education.

If public access is permitted at Tule Ponds in the future, pedestrian-friendly access from the nearby BART station would need to be installed. Currently, a visit to the site from the Fremont

BART station involves an exposed traverse of a multi-acre surface parking lot with no clearly marked walkways. A narrow, inexpensive tree-lined path through the parking lot has great potential to attract transit users to the wetlands. In addition, neither the BART parking area nor the surface parking lot at the southern end of the Tule Ponds site contain significant BMPs to treat runoff before it enters the wetlands. Small, inexpensive storm water management features, like swales, gravel strips, and impervious paving would be excellent educational tools in the context of treatment wetlands, and if designed properly could provide real water quality benefits.

CONCLUSION

To date, a number of stormwater ponds have been built in the Bay Area, but only the Demonstration Urban Stormwater Treatment (DUST) marsh in Fremont has been extensively monitored for success (Woodward-Clyde, 1998). In general, Tule Ponds function as planned but are too deep in the wet months and exhibit signs of slope instability, hypoxia, and eutrophication. There are many bird ,amphibian, and insect species that use the site. We were unable to find specific water treatment or habitat goals for this project, which would benefit the evaluation of future stormwater BMPs. It is critical to observe and evaluate these systems to ensure that future ponds can successfully integrate multiple uses, including open space, wildlife habitat, and recreational areas. This study serves as a template for an initial, rapid evaluation of constructed stormwater wetlands.

While our study is an example of a short and intensive site survey examining what measurements could be made within a one or two day site visit and outlines some of the useful inferences that can be drawn from such observations, we believe agencies and universities should collaborate and conduct formal evaluations on a handful of stormwater ponds and wetlands that vary in size and drainage. Such an investigation could address the hydrological, pollutant removal, ecological, and public use benefits of these system so that new stormwater control efforts can maximize limited financial and spatial resources.

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Table 1. Common Evaluation Methods

Evaluation Approach

To gain a better understanding of evaluation criteria for stormwater treatment wetlands, we reviewed websites, papers, and BMP manuals with information about wetland monitoring. Common approaches to evaluate the success of stormwater treatment wetlands include:

Measuring Inflow and Outflow (Comings et al., 2004)

- Where polluted stormwater enters the wetland in a discrete location, and treated water exits in a specific place, it is useful to measure chemical and physical differences in water quality
- Long term studies measure these variables over multiple storm events (FHWA, 2005; Center for Watershed Protection, 2003; and Rogue River Project, 2000).
- In this study, we considered inflow/outflow sampling at Tule Ponds, but the site was not conducive to this common approach since there are multiple water inputs and most of the outputs are into groundwater.

Water Chemistry (Comings et al., 2004)

- Chemicals being removed: Petrochemicals, heavy metals (arsenic, zinc, lead, nickel), chemicals associated with fertilizers (nitrogen and phosphorous), and total suspended solids
- Indicator variables: salinity, temperature, dissolved oxygen, and conductivity
- In this study we focused on indicators due to time and budget constraints yet to definitively characterize efficacy one must sample the target pollutants

Detention Time

- There is a positive relationship between the amount of time the water remains in the system (detention time, or hydraulic residence time) and the pollutant removal effectiveness of the wetland (FHWA, 2005; Comings et al., 2004).
- Measuring detention time in Tule Ponds is not plausible due to the complex hydrology at the site.

Physical Measures

- The physical structure of treatment wetlands is an important component of project follow-up surveys.
- Characterizing treatment ponds is done via surveying cross section and long profiles, vegetation cover, slopes, and high water marks
- Serves as indicators for functions, including: value to wildlife; water circulation; biofiltration of nutrients; and flood capacity (Center for Watershed Protection, 2003).
- We conducted surveys of pond topography, vegetation variation, high water marks, and water level to better understand the physical qualities of Tule Ponds.

Table 2. Results from spatial survey and comparison to engineering plans and recommendations by the Bay Area BMP guideline.

	Planned (ft)	Observed (ft)	Difference*	Recommended**
Pond A				
Bed elevation	37.07	38.76	1.69	-
Water depth	9.85	9.43	0.42	3-9 ft
Water surface elevation	46.92	48.19	1.27	-
Bench east	6.6	4.6	-2.0	-
Bench west	6.6	5.1	-1.5	-
Upper west slope	2.0 to 1	2.6 to 1	shallower	4:1 or shallower
Lower west slope	1.5 to 1	1.89 to 1	shallower	4:1 or shallower
Lower east slope	1.5 to 1	2.1 to 1	shallower	4:1 or shallower
Upper east slope	2.0 to 1	2.0 to 1	same	4:1 or shallower
Inlet 1				
Water depth	n/a	5.62	-	
Bridge elevation	48.23	48.67	0.44	-
Water surface width	13.12	50	36.88	-
Thalweg	42.65	42.56	-0.09	-
Water surface elevation	n/a	48.18	-	-
West slope	2 to 1	2.04 to 1	same	4:1 or shallower
East slope	2 to 1	1.94 to 1	same	4:1 or shallower
Pond B				
Bed elevation	36.42	37.85	1.43	-
Water depth	9.84	10.1	0.26	3-9 ft
Water surface elevation	46.26	47.95	1.69	-
Bench East width	6.6	4.0	-2.6	
Bench West width	6.6	6.0	-0.6	
Island elevation	47.74	48.1	0.36	-
Upper east slope	2.0 to 1	2.7 to 1	shallower	4:1 or shallower
Lower east slope	1.5 to 1	2.5 to 1	shallower	4:1 or shallower
East island slope	1.5 to 1	1.8 to 1	shallower	4:1 or shallower
West island slope	1.5 to 1	2.48 to 1	shallower	4:1 or shallower
Upper west slope	1.5 to 1	1.9 to 1	shallower	4:1 or shallower
Lower west slope	2.0 to 1	2.6 to 1	shallower	4:1 or shallower
Inlet 2				
Water depth	n/a	6.25	-	-
Bridge elevation	48.88	48.95	0.07	-
Water surface elevation	n/a	47.77	-	-
Water surface width	n/a	50	-	-
Thalweg	n/a	41.52	-	-
East slope	2.0 to 1	2.01 to 1	same	4:1 or shallower
West slope	2.0 to 1	1.69 to 1	steeper	4:1 or shallower

Pond C				
Bed elevation	39.37	39.16	-0.21	-
Water depth	6.56	8.61	2.05	3-9 ft
Water surface elevation	45.93	47.77	1.84	-
Island 1 mean elevation	47.74	47.77	0.03	-
Island 2 mean elevation	47.24	47.31	0.07	-
East slope	1.5 to 1	1.6 to 1	same	4:1 or shallower
East island slope	1.5 to 2	2.5 to 1	shallower	4:1 or shallower
West island slope	1.5 to 3	1.9 to 1	shallower	4:1 or shallower
West slope	1.5 to 4	1.4 to 1	same	4:1 or shallower

*Observed-Planned ** SWQTF 1993

Table 3. Size and volume of Tule Ponds*

	Depth (ft)	Length (ft)	Mean Width (ft)	Volume (ft^3)	Surface Area (ft^2)	(acres)
Pond A	9.43	443	72	91,887	31,969	0.73
Pond B	9.8	131	115	45,013	15,069	0.35
Pond C	8.6	131	115	39,501	15,069	0.35
Inlet 1	5.6	66	20	1,102	1,292	0.03
Inlet 2	6.25	131	20	2,461	2,583	0.06
TOTAL				179,964	65983	1.51

*width and length taken from plans, depth from actual measurements

Table 4. Water chemistry on April 7, 2006 taken at 0.8 ft deep with hand held probe.

Site	Location	Temperature (°C)	Dissolved Oxygen (mg/L)	Conductivity (uS/cm)	Salinity (ppt)
Inflow from Tule South		15.2	5.30	666	0.3
Mix with Tyson	-	15.0	4.64	236.6	0.1
Pond C	South	16.7	7.98	64.7	0.0
Pond C	North	16.6	8.30	64.7	0.0
Pond B	South	15.5	7.20	59.4	0.0
Pond B	North	16.3	7.50	62.0	0.0
Pond A	South	15.4	6.48	57.5	0.0
Pond A	North	15.5	6.60	58.2	0.0
Inflow are Pond A	-	15.4	6.70	58.0	0.0
West side of Tyson	-	15.7	7.25	246.9	0.1

Figure Legend

Figure 1. Location Map

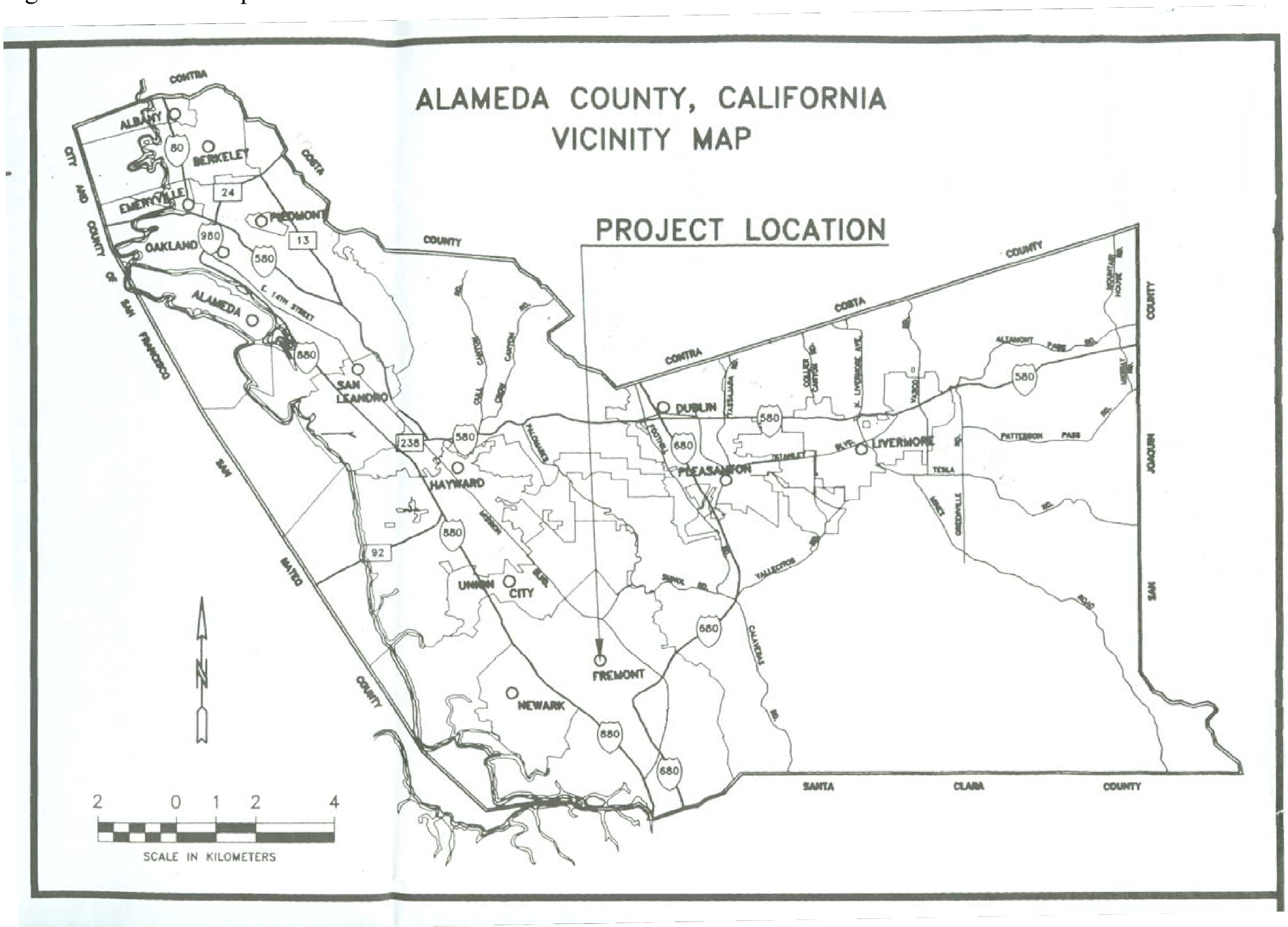

Figure 2. Watershed Map

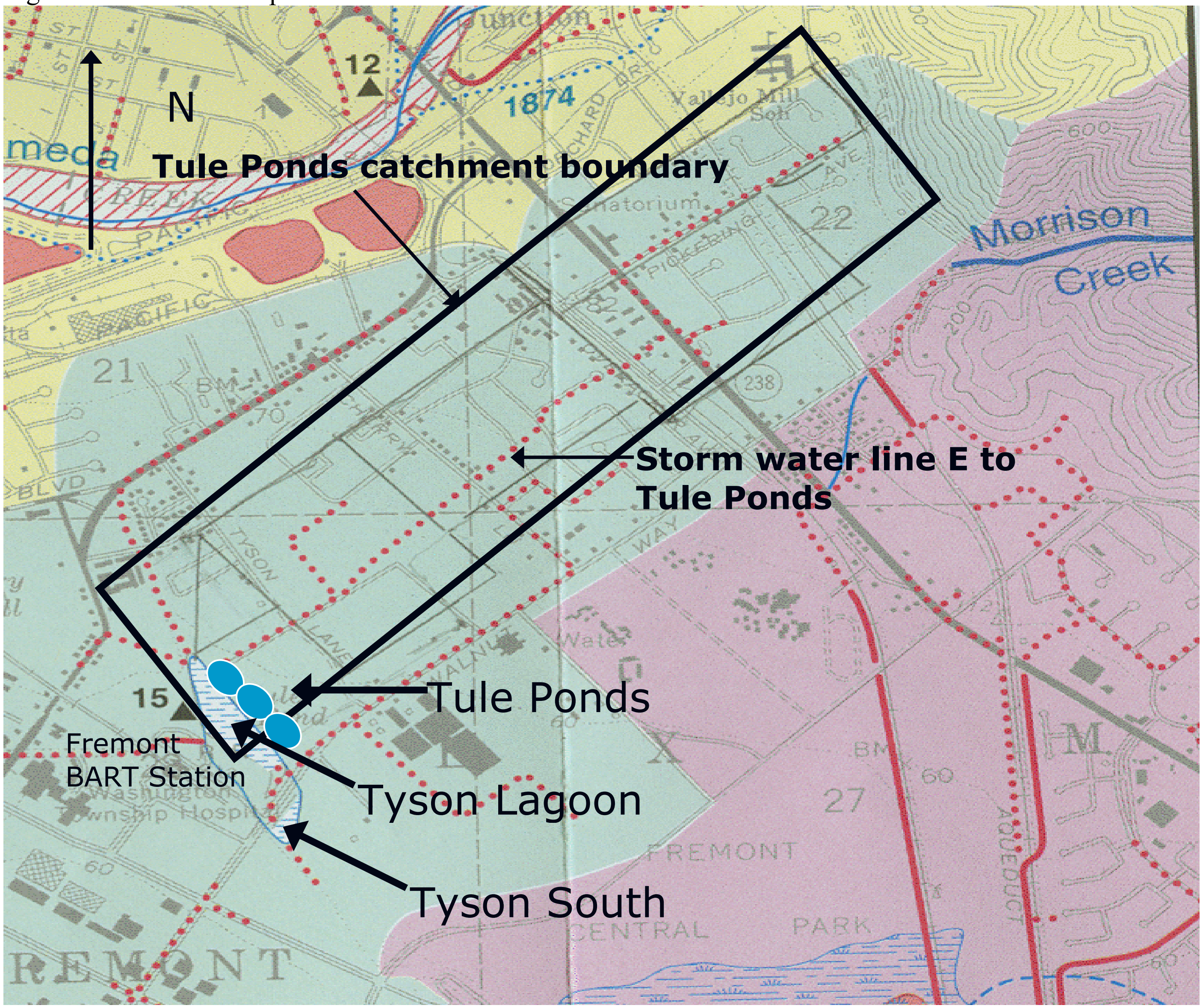

Figure 3. Detailed engineering plans with location of cross sections, water samples, and indented flow. Outflow leads to Tyson Lagoon, which is due west of the Tule Ponds.

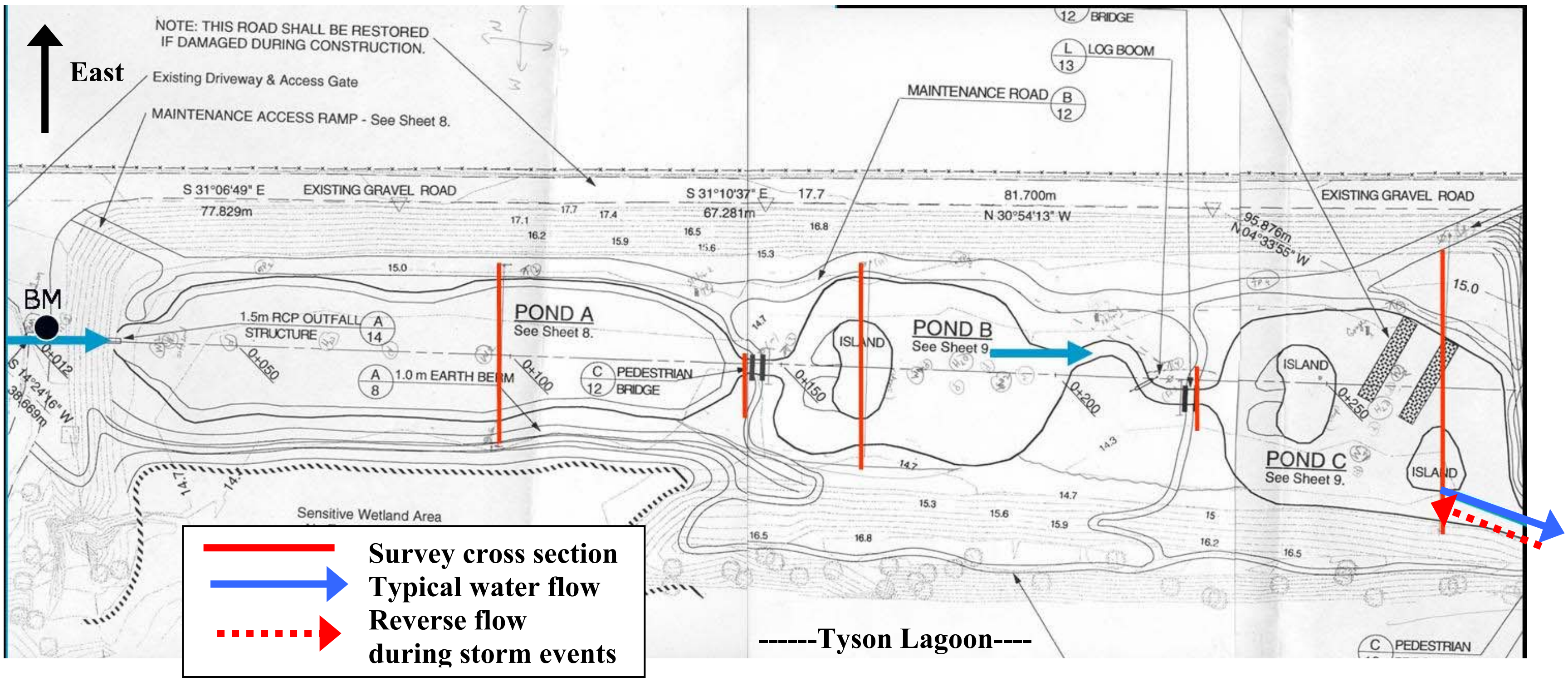

Figure 4

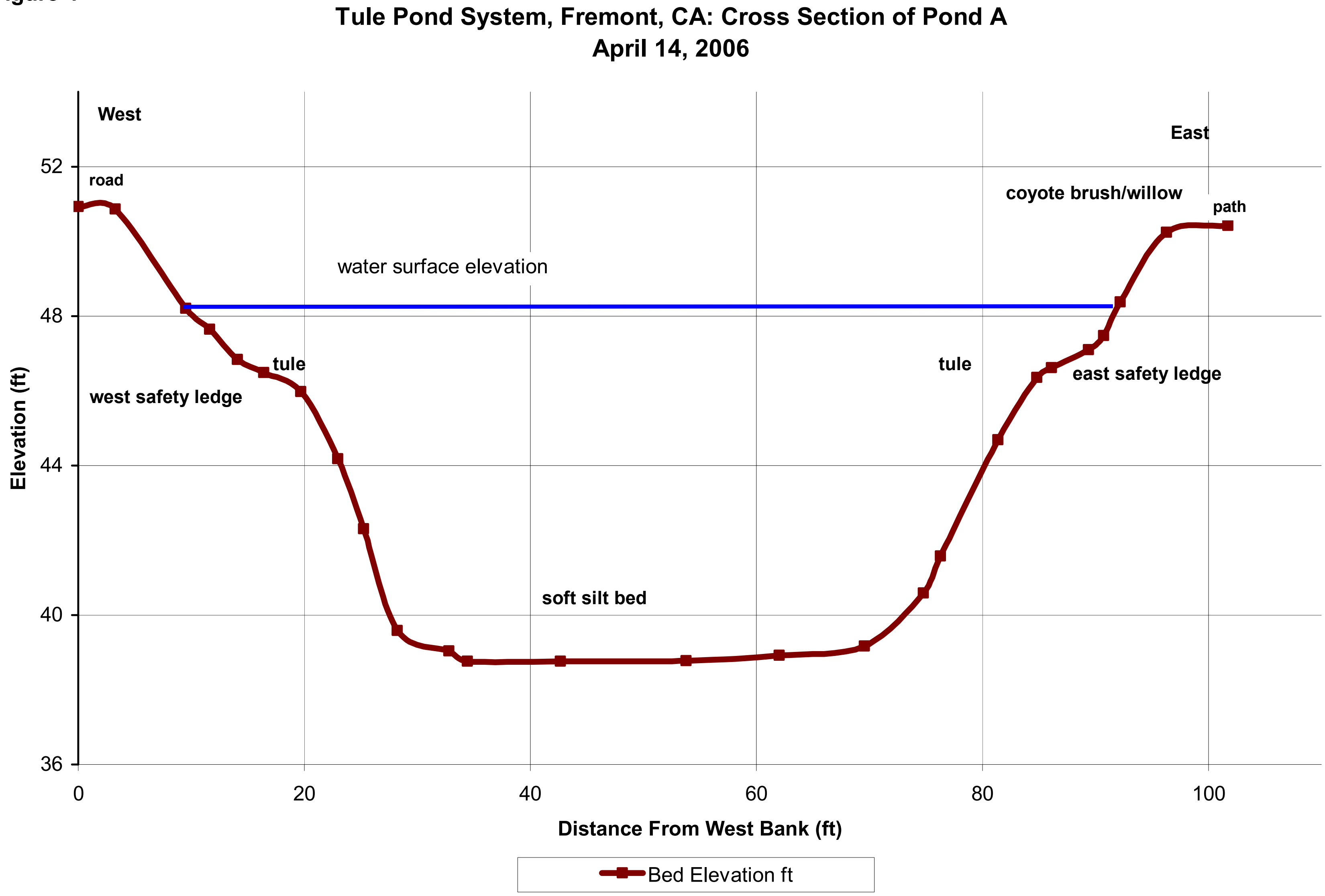
Tule Pond System, Fremont, CA: Cross Section of Pond A
April 14, 2006
West
East
road
coyote brush/willow
path
water surface elevation
tule
west safety ledge
tule
east safety ledge
soft silt bed
Elevation (ft)
52
48
44
40
36
0
20
40
60
80
100
Distance From West Bank (ft)
Bed Elevation ft

Figure 5

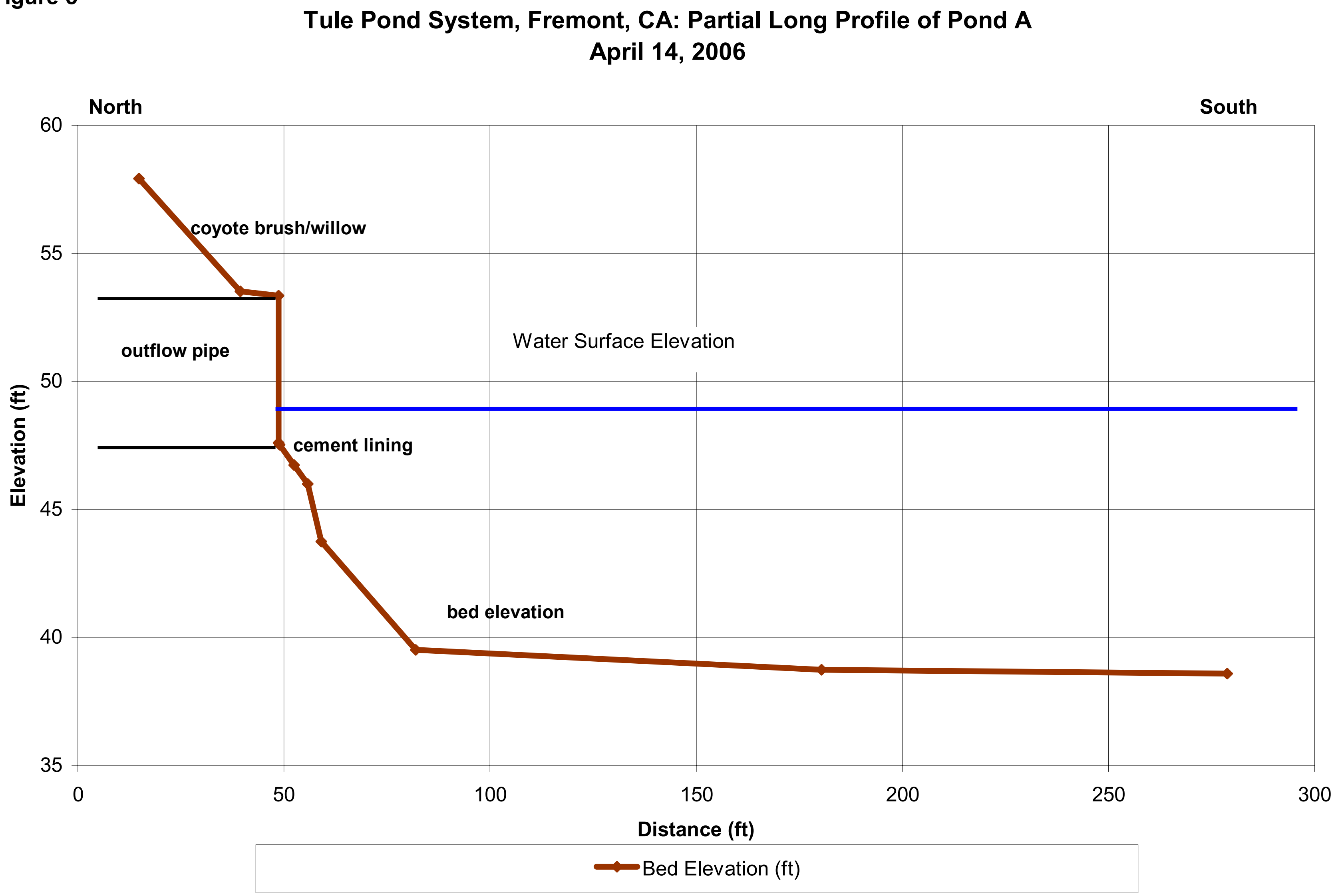
Tule Pond System, Fremont, CA: Partial Long Profile of Pond A
April 14, 2006
North
South
coyote brush/willow
outflow pipe
Water Surface Elevation
cement lining
bed elevation
Elevation (ft)
60
55
50
45
40
35
0
50
100
150
200
250
300
Distance (ft)
Bed Elevation (ft)

Figure 6

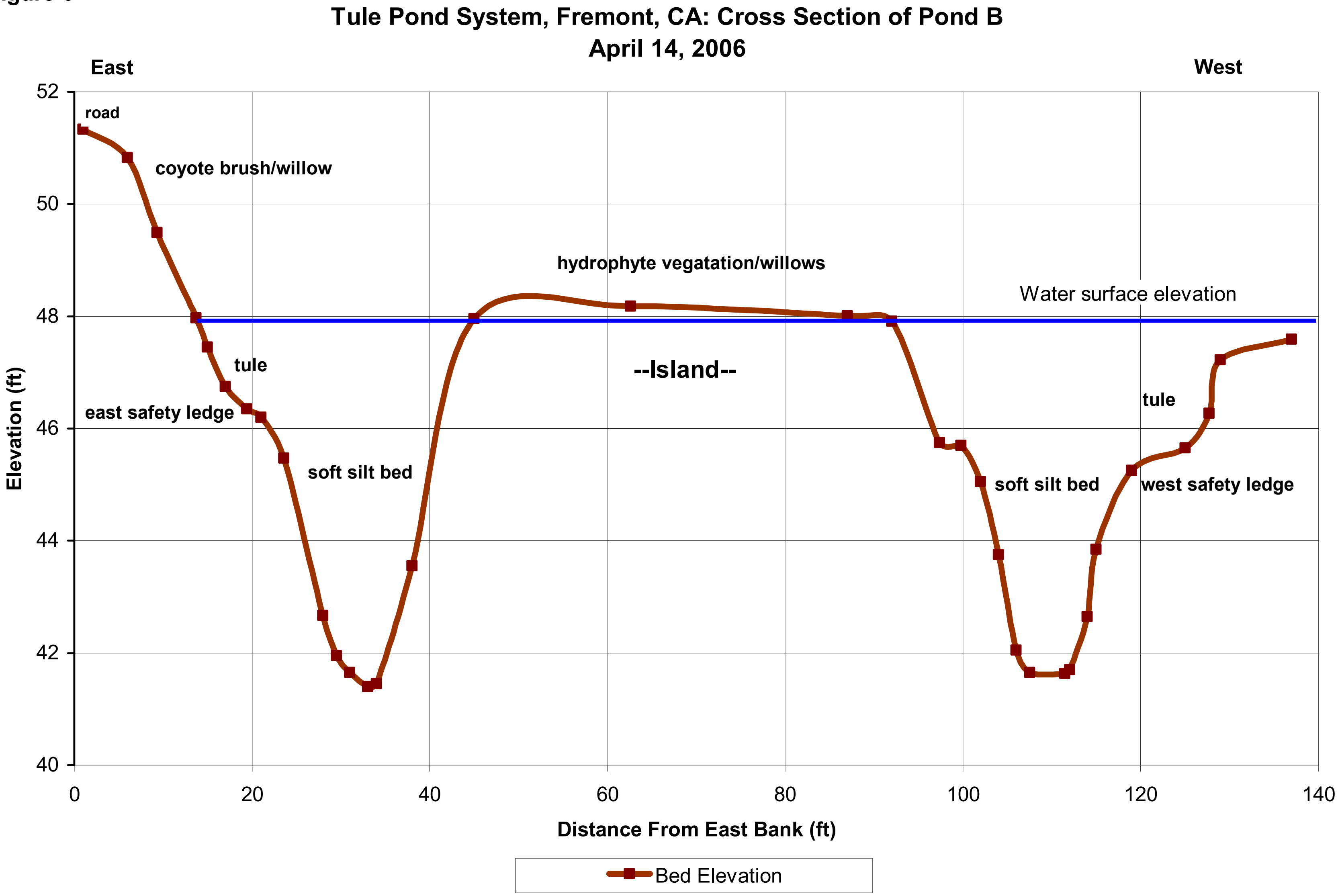
Tule Pond System, Fremont, CA: Cross Section of Pond B
April 14, 2006
East
West
road
coyote brush/willow
hydrophyte vegatation/willows
Water surface elevation
tule
--Island--
east safety ledge
tule
soft silt bed
soft silt bed
west safety ledge
Elevation (ft)
52
50
48
46
44
42
40
0
20
40
60
80
100
120
140
Distance From East Bank (ft)
Bed Elevation

Figure 7

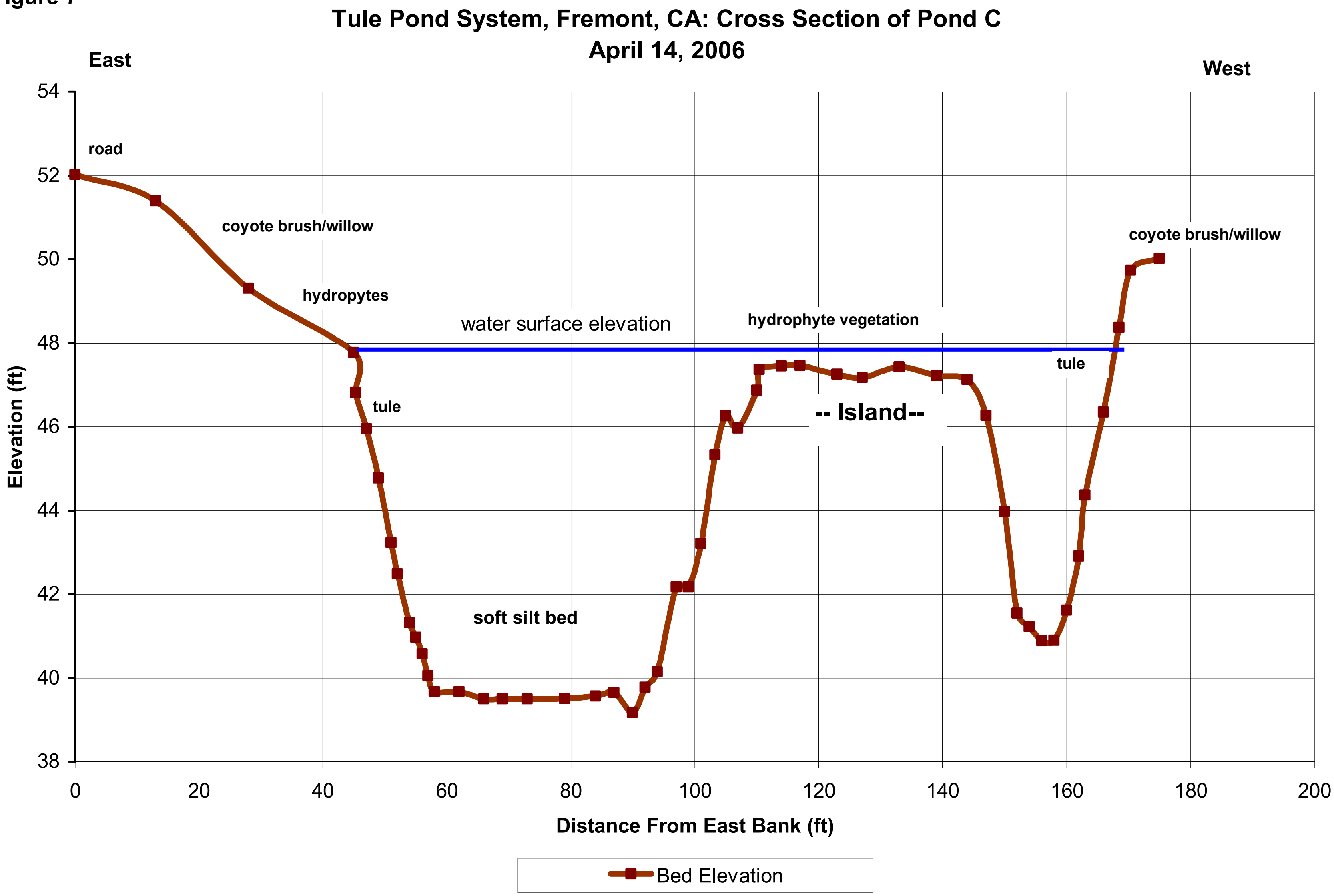
Tule Pond System, Fremont, CA: Cross Section of Pond C
April 14, 2006
East
West
road
coyote brush/willow
hydropytes
water surface elevation
hydrophyte vegetation
coyote brush/willow
tule
tule
-- Island--
soft silt bed
Elevation (ft)
54
52
50
48
46
44
42
40
38
0
20
40
60
80
100
120
140
160
180
200
Distance From East Bank (ft)
Bed Elevation

Figure 8

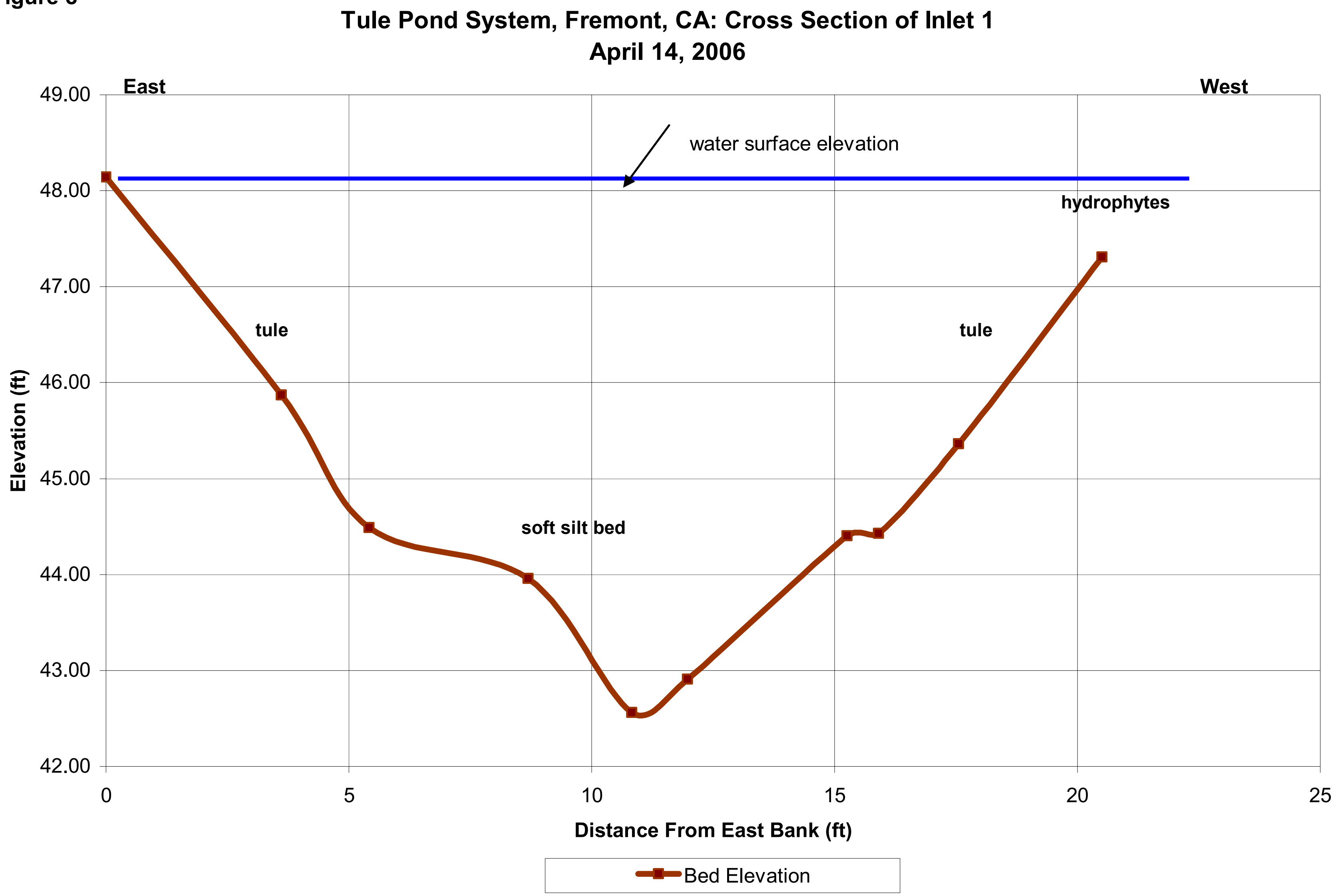
Tule Pond System, Fremont, CA: Cross Section of Inlet 1
April 14, 2006
East
West
water surface elevation
hydrophytes
tule
tule
soft silt bed
49.00
48.00
47.00
46.00
45.00
44.00
43.00
42.00
Elevation (ft)
0
5
10
15
20
25
Distance From East Bank (ft)
Bed Elevation

Figure 9

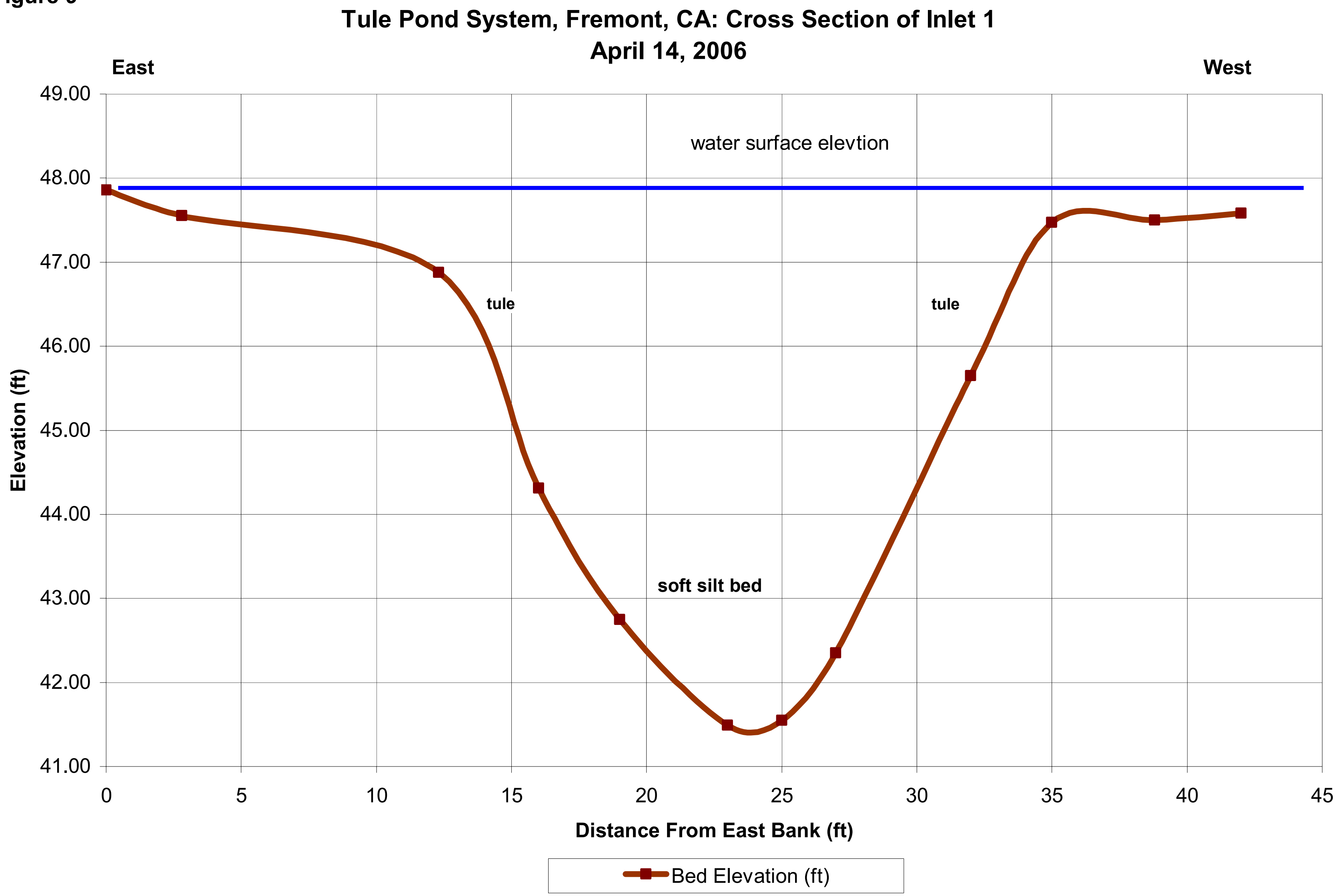
Tule Pond System, Fremont, CA: Cross Section of Inlet 1
April 14, 2006
East
West
water surface elevtion
tule
tule
soft silt bed
Elevation (ft)
49.00
48.00
47.00
46.00
45.00
44.00
43.00
42.00
41.00
0
5
10
15
20
25
30
35
40
45
Distance From East Bank (ft)
Bed Elevation (ft)

Figure 10. Water chemistry results at two depths below water surface elevation.

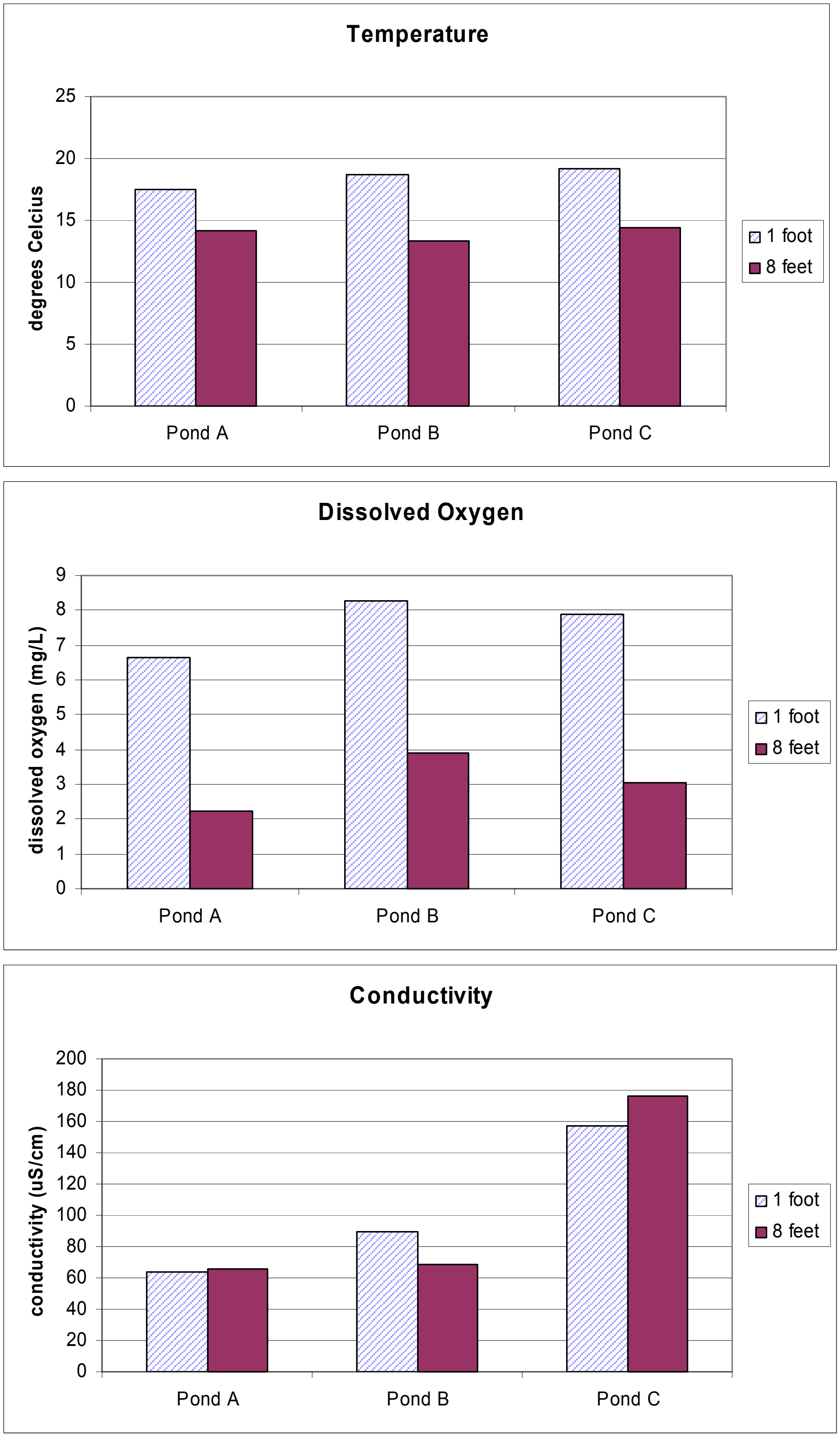

Photo 1. Photo taken of Pond A from the north end with main pipe inflow (bottom). We had to boat around the pond to survey the dimensions and take water chemistry readings. The thin ring of tule vegetation around the pond edge is growing mostly on an engineered “safety ledge”.

Photo 2. We conducted cross section measurements along a fixed transect line using a row boat. This proved to be challenging, especially when winds were high.

Photo 3. Typical land survey procedure measuring elevation of features such as the road. Pond C Island 2 in the background which is just below water level at the time of sampling.

Photo 4. Example of survey level used to measure elevation.

Photo 5. Pond C in the foreground surrounded by housing. The lower road is designed to allow vehicle access to the ponds for maintenance. Note that the entire area can handle much larger inflow during large storm events

Photo 6 . From Pond A the BART Fremont stop is clearly visible. The visible water is Tyson Lagoon, a sag pond adjacent and hydrologically connected to the Tule Ponds during the wet season.

Photo 7. Example of hydrophytic vegetation common to the shallows (0.2 to 0.6 ft below water surface elevation) as seen here, and also on the islands. Treefrog tadpoles were abundant in this area. This area, including a path, was not designed to be under water.

Appendices

Appendix A: Urban Storm Water Concerns and Regulations

Urbanization has changed the typical stream hydrograph, which can have biological as well as have physical downstream impacts (Kondolf & Keller, 1991; Wang 2001, Brown et al., 2005). Reduced infiltration leads to larger peak flows in streams, resulting in more frequent and severe downstream floods. Further, more water in these streams causes erosion, resulting in bank destabilization and streambed incision.

The National Pollutant Discharge Elimination System (NPDES) was established as part of the Federal Water Pollution Control Act Amendments of 1972. A 1987 revision of the legislation requires cities with more than 100,000 people to control the amount of pollution entering local storm drain sewer systems. In 1989, a group of 17 county and city agencies established the Alameda Countywide Clean Water Program (ACCWP) to comply with the mandated pollution control requirements. Guidelines for managing, monitoring, and reducing urban runoff were established through the NPDES. The ACCWP developed a Storm Water Management Plan to meet objectives from both the NPDES permit and the Bay Basin Plan, which was developed by the San Francisco Regional Water Quality Control Board (RWQCB) to prevent urban runoff pollution and to help restore the health of local creeks and San Francisco Bay.

New storm water management approaches recommended by agencies like RWQCB incorporate “green technologies” to detain storm water, remove pollutants, mitigate for floods, and protect the integrity of aquatic ecosystems, all while providing an open space or landscape amenity to the community. There are many BMPs designed for these purposes, including vegetated swales, extended detention basins, and storm water ponds/constructed wetlands (SWQTF, 1993). The advantages and disadvantages of each depend on the space and money available, the amount of water to be treated, the chemical or physical constituents to be removed, as well as the personal preferences of people involved in their design (Minick, 2004). Storm water ponds, for example, are extremely successful in removing pollutants and provide additional habitat for aquatic wildlife, but require ongoing maintenance, and may be a source of disease vectors (SWQTF, 1993; Walton 2003). All too often, once designed and implemented, BMPs are assumed to be a success despite a lack of follow-up or monitoring data.

Appendix B: Wildlife

While at the site, we observed American bullfrog (*Rana catesbeiana*) adults, Pacific treefrogs (*Hyla regilla*) adults and tadpoles, adult damselflies, dragonflies, two snowy egrets (*Egretta thula*), mallards (*Anas platyrhynchos*), Canada geese (*Branta Canadensis*), and raccoon (*Procyon sp.*) prints. We did not see mosquitofish (*Gambusia affinis*) though Blueford said the pond was stocked with it for mosquito control. Most *H. regilla* tadpoles were observed in the area by Bridge 2 that was originally planned to be dry land but was inundated with 0.2-0.6 ft of water during our site visit, and based on observed vegetation, this area likely floods each wet season. Egrets fed on Island 2 within Pond C later in the afternoon where many dragonflies were observed. Western pond turtles (*Clemmys marmorata*) were observed at the site; several individuals have been introduced by Blueford in order to start a reproductive population.

Since construction, the bridges have remained at their intended levels, yet part of Bridge 2 and the west side trail were underwater. While this initially sounds like a problem, it turns out to be a benefit for tadpoles since the area west of Bridge 2 was where the majority of the Pacific treefrog tadpoles were located and was the major range of the hydrophytes in addition to the islands. Tadpoles prefer warmer waters near the surface that provide a good amount of algae as a food source and facilitate rapid growth (KBL, personal observation). Other amphibian species common to lentic sites, western toads (*Bufo boreas*) and newts (*Taricha spp*.), were not present at Tule Ponds, which could be due to a lack of colonization potential as these species are not as good at dispersing as bullfrogs and treefrogs (Stebbins, 1985). Alternatively, these species may require different habitat conditions not present at this site.

The island heights were nearly the same as the planning documents, and the small variation in their elevations (0.4 ft) are a boon for wildlife even though during the wet season Island 2 in Pond C is under water. The variation in levels provides habitat heterogeneity; while the pond level subsides in summer or increases in the winter, there are different shallow area where egrets and mallards can forage or hunt depending on the water level. During our survey the pond surface area was 4300 ft^2 larger than planned because of recent rain events and the temporary flooding around the inlets connecting the three ponds. It was interesting to note that we did not observe any aquatic snails, which is strange for a wetland system. Snails are grazers and can convert a large degree of plant biomass and pass this carbon up the food chain. It is possible that annual desiccation of the wetland prevents summer survival of snails.