A Study of Shallow Groundwater Migration through Anthropogenic Fill along a Seawall

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EXECUTIVE SUMMARY

This report provides the findings and opinions of a historical document review, hydraulic balance calculation, and proposed additional study for a property that was historically used as a bulk petroleum storage and distribution facility. The property lays along the base, west, of a heavily vegetated bluff with a tidally influenced body of water west-adjacent of the property. The western portion of the property is bounded by a seawall spanning approximately 3,200 linear feet trending north-south. The seawall's construction details are not known, save for a 225-foot section of driven sheet pile wall located within the northern portion of the property's seawall. Due to the presence of petroleum hydrocarbons in soil and groundwater at the property, a cleanup action for the property will likely be overseen by the state regulatory agency. The property is currently undergoing remedial investigation in an effort to identify the lateral and vertical extent in which contaminants at the property have come to be located, also known as the "site" as defined by the Model Toxics Control Act (MTCA). The majority of the property bounded within the seawall area has been characterized; however, the shoreline sediments located immediately west-adjacent of the seawall have not been properly delineated. Identifying the bounds of the site to the west within sediment is pivotal for the purposes of the remedial investigation. Since the west-adjacent shoreline is so extensive, conducting a complete sediment sampling event along the entire shoreline would be cost-prohibitive due to analytical costs and logistical issues at the property. Because of the extensive nature of the shoreline, it would greatly benefit the client and project to focus sampling efforts at areas of greater risk for contaminants along the shoreline by identifying potential preferential pathways for contaminants to migrate off of the property and into adjacent shoreline sediments.

The review of historical studies of the property yielded some useful information; however much of the findings included within the historical studies were lacking original raw data, therefore limiting the information obtained. The calculated hydraulic balance for the property yielded a relatively large surplus of recharge to groundwater after precipitation events, reinforcing the concept that contaminant have potentially historically, and currently, been migrating into the adjacent shoreline through preferential pathways along the seawall. Due to the limitation within the historical studies for the property as well as the groundwater recharge identified in the hydraulic balance, an additional study was proposed in an effort to provide additional aquifer characteristics along the seawall, and the ability to observe flow propagation at and proximate to the seawall in two-dimensions through time without the need to piece separate studies together. This proposed study includes a single simultaneous tidal study which comprises select monitoring points along the seawall.

This report has identified the need for additional data that can be collected through available avenues for the property based upon the client's desires and project needs. Ultimately, the proposed additional study is suggested based upon its relatively low capital investment, and ability meet the requirements relevant to the specific project needs and scope. Assuming preferential pathways are identified through the additional study proposed within this report, a representative and cost-effective sediment sampling plan can then be put in place in an effort to define the site.

1.0 INTRODUCTION

I appreciate the opportunity to present this Study of Shallow Groundwater Migration through Anthropogenic Fill along a Seawall (project) prepared in partial fulfillment of the requirements for the degree of Master of Science - Earth and Space Sciences: Applied Geosciences (MESSAGe) at the University of Washington (UW) located in Seattle, WA. Due to the current state of the property evaluated during the course of this project, information regarding the property's location or specific historical information may not be divulged. This constraint of information is solely placed upon information which may compromise the confidentiality of the property, and in no way will hinder the results of this project.

Petroleum products have been a driving force in our economy for well over a century; unfortunately the storage and transportation of these materials such as gasoline, oil, diesel, and unrefined crude oil have not always been guided by environmentally driven regulations. Due to these previously recognized standards, many unwarranted releases of various petroleum hydrocarbons, solvents, and other potentially harmful constituents have occurred during the industrialization of the United States.

The property investigated during the course of this project was historically used for the bulk storage of various petroleum hydrocarbons. The property is approximately 65 acres in size and located east-adjacent of a large body of tidally influenced salt-water. The property is located west of a heavily vegetated bluff. The primary focus area for this study is along the western portion of the property where a seawall, trending north-south, spans approximately 3,200 linear feet along the adjacent body of water and shoreline. The majority of the seawall does not have documentation on its construction. A site plan depicting the property is provided as Figure 1.

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1.1 PROJECT PURPOSE AND OBJECTIVE

Due to the previously identified concentrations of petroleum hydrocarbons and separate phase hydrocarbons (SPH) in soil and groundwater at the property, a regulatory cleanup action overseen by the state regulatory agency will most-likely need to be undertaken by the property owner as a means to properly mitigate the potential hazards resultant from the concentrations of petroleum hydrocarbons at the property. In order to properly identify the most efficient form of mitigation at the property, the "site" must be properly delineated both laterally and vertically. The "site" is defined by the Model Toxics Control Act (MTCA) as the vertical and lateral extent of where contaminants of interest have come to be located. Due to the property's location, sediment sampling of the adjacent shoreline is very important to the future investigation, site delineation, and mitigation planning. The adjacent body of water is a sensitive receptor and should be prioritized during the potential cleanup action.

Due to the adjacent shoreline's length (approximately 3,200 linear feet), conducting sediment sampling along the entirety of the shoreline would be cost-prohibitive within the scope of the project. Therefore, the goal is to identify specific sampling locations which would allow for a more cost-effective sediment sampling plan in an effort to define the site. To allow for a more refined sediment sampling plan it is important to identify the presence of preferential migratory pathways for contaminants to potentially migrate off of the property through the seawall. It is possible for excess water which is introduced into the subsurface of the property to migrate through or around the seawall and bring contaminants along with it. The objectives of previous studies completed at the property were primarily developed in an effort to evaluate hydrologic characteristics of the portion of the property that is bounded within the area of the seawall, and do not provide many raw data that can be interpreted for the purposes of this project.

The objective of this report is to review and evaluate historical reports and memorandums prepared for the property, calculate a hydraulic balance for the property, and identify what results of the historical study review and hydraulic balance may be useful when identifying preferential pathways in an effort to propose the most efficient sediment sampling event. Upon analysis of information gathered, calculated, and reviewed; additional study will be proposed with the specific intentions of filling data gaps resultant from previous studies at the property and observing the propagation of flow through and around the seawall during at high and low tide conditions in an effort to characterize potential preferential pathways for groundwater to migrate off of the property.

It is important to note that this study is solely intended to provide a broad view of the hydraulic characteristics of the property. The work completed within this study is merely a small portion of the scope of work for the project as a whole, and therefore has limitations of its own (described in §8). This study will provide information designed to further develop a sediment sampling plan during the remedial investigation process, and does not identify or represent any portion of a feasibility study, cleanup action plan, or closure by no further action of the property. The complexities of the contaminant issues at the property remain under investigation, and the evaluation of potential cleanup actions would prove to be fruitless at this point in time.

2.0 SCOPE OF WORK

The scope of work completed during the course of this report includes the review and analysis of several studies previously conducted on the property, as well as the development of a hydraulic balance for the property. Upon completion of the review and analysis of the previous studies and the hydraulic balance for the property, a scope of work was proposed that incorporates the findings of the historical review and hydraulic balance calculated for this report.

2.1 HISTORICAL STUDY REVIEW

The review of the previous investigations was intended to provide insight to the expected conditions at the property and to evaluate what additional data need to be collected in order to develop a sediment sampling plan suitable for the project's needs. The previous studies do not implicitly focus on hydraulic activity along the seawall; however, select information from the previous studies was used as supplementary data for the proposed additional work for this project.

2.2 HYDRAULIC BALANCE

A hydraulic balance was calculated to evaluate the input versus output of water at the property within the shallow water bearing zone. Data including precipitation, evaporation, permeability, and groundwater pumping operations at the property were taken into account to provide an estimated minimum amount of water that is introduced into the property's subsurface through precipitation over the course of a year (2014). The purpose of completing a hydraulic balance for the property was to understand the balance of groundwater at the property on the most rudimentary level, and was calculated in order to obtain a baseline for recharge and discharge at the property to be used and refined for reference as needed.

2.3 PROPOSED ADDITIONAL HYDROLOGIC STUDY

The previous study of the property with relation to tidal fluctuations was developed in an effort to observe and interpret groundwater flow through the area of the property bounded within the seawall. The previous tidal study included several wells located along the seawall; however these data were collected over the course of three separate 72-hour tidal study events, and much of the findings produced in the historical reports reviewed do not provide the raw data which allows for limited interpretation for this report. It is in the interest of the client and SLR International Corporation (SLR) to capture tidal fluctuations along the seawall through a single simultaneous event. The single event will allow the potential to evaluate data collected through completely known sources and bounds of error, while allowing the potential to reference or include historical data (previous studies) for supplementary purposes. The additional study will be focused primarily on the interaction of groundwater along the seawall with respect to discrete monitoring points relative to one another.

3.0 PHYSICAL SETTING

3.1 PROPERTY DESCRIPTION

The property is a large industrial parcel located at the base of a bluff formed from glacial processes. The study area of the property is primarily composed of anthropogenic fill which was placed at the property in order to create a solid substrate to be capable of housing large storage tanks for various petroleum hydrocarbons. The anthropogenic fill is composed of sands, gravels, and silts; however, due to its sporadic nature and varied density across the property, there is little to no assumed geologic continuity. The property is pseudo-ellipsoidal in shape trending north-south, and approximately 50% of the property's surface is permeable.

The seawall along the western portion of the property does not appear to have any obvious seeps or pathways for groundwater to depart the property. The northern portion of the seawall is constructed of concrete to an unknown depth and a 225-foot sheet pile wall that was driven to a depth of approximately 25 feet below ground surface (bgs). Rip-rap visually covers the northern portion of the seawall making it difficult to assess the current state of the seawall at that portion of the property. The seawall at the central portion of the property is of concrete construction and unknown depth. Approximately 4 to 6 feet of the seawall is visible in the central portion of the property from the shoreline and does not appear to have any obvious seeps or pathways for groundwater to travel at or above ground surface. The southern portion of the seawall along the property is of wooden construction; however, the construction of the seawall beneath the wooden portion of the seawall is unknown.

3.2 PROPERTY HISTORY

The property was constructed circa 1912, and was historically used as an asphalt refinery and light products/lube oil distribution facility. Petroleum products historically used at the property, included crude oil, asphalt products, lubrication oils, fuel oils, aviation fuels, motor vehicle fuels, and marine vessel fuels. Although a majority of the operations on the property have ceased, the property is currently used for the storage and distribution of marine fuels and asphalt.

3.3 HYDROLOGIC CONDITIONS

The property is primarily composed of anthropogenic fill that was imported during the development of the site as a means to properly construct the structures erected at the property. The southern portion of the property is constructed upon a salt marsh that was present prior to the development of the property. The remainder of the property is built on top of what is presumably tidal deposits and upland bluff erosion. The property's primary source of groundwater recharge is from direct precipitation.

Due to previous groundwater studies, and the property's location adjacent to a large tidally influenced body of water, one can assume that groundwater at the property is influenced by tidal fluctuations; however, the seawall creates a barrier which alters the natural tidal interactions at the property. The completion of this report (and the additional study proposed herein) will hopefully assist in understanding the amount in which tidal fluctuations influence the fate of the property's groundwater, and its potential to travel throughout various areas of the seawall. The southern portion of the property appears to have a deeper aquifer stratigraphically located beneath the aforementioned salt marsh deposits. The shallow groundwater zone at the property appears to be contained within the anthropogenic fill.

The presence of deeper water-bearing zones in the central and northern portion of the property is unknown; however, new data collected from deeper monitoring wells during the proposed additional study will assist in the evaluation of potential deeper water-bearing zones at the property. The shallow aquifer located at the southern portion of the property has an estimated saturated thickness of 10 feet based upon the elevation of water relative to the historical salt marsh deposits that act as a confining layer. The shallow water-bearing zones in the northern and central portion of the property have an estimated saturated thickness of 20 feet based upon an assumed interface between the anthropogenic fill and natural deposits. The northern and central portions of the property may have unconfined aquifers which extend well beyond the estimated extent. This potential for extended unconfined aquifers at the northern and central portion of the property will be addressed upon completion of the additional study by comparing data collected from the appropriate selected deep and shallow relative to one another.

3.4 CURRENT ON-SITE ENVIRONMENTAL ACTIVITIES

The property currently operates a groundwater pump-and-treat system which draws from five separate wells located in three areas of the property. Two wells are located in the southern portion of the property, two in the central portion, and one in the northern portion. Each well pumps groundwater through a dedicated submersible pump at a rate of approximately one gallon per minute (gpm) that is calibrated once every week.

The extracted water moves through a treatment system which includes an oil/water separator, bioremediation tanks, as well as a settling and a pumping tank prior to being discharged into the adjacent body of water under an industrial National Pollutant Discharge Elimination System (NPDES) permit. Laboratory analytics are completed on samples collected from the system on a monthly basis as a requirement of the permit. Due to its continuous pumping, the system pumps and treats approximately 7,200 gallons of groundwater per day (equating to approximately 2,628,000 gallons of groundwater per year). A figure depicting the current features located on the property is presented as Figure 2.

4.0 METHODS

4.1 HISTORICAL STUDY REVIEW

This portion of the report includes the review of previously prepared documents for the property that contain information regarding tidal influence and hydrologic properties at the property. The documents reviewed for this study are listed as follows:

- 2005 Groundwater Investigations, Client/Site Confidential. Prepared February 16, 2006. (GI 2006)
- Potential SPH Migration – North End of Asphalt Plant Seawall, Client/Site Confidential. Prepared February 22, 2006. (SPH 2006)
- Evaluation of Separate-Phase Hydrocarbons – January 2007: Asphalt Plant Area, Client/Site confidential. Prepared February 6, 2007. (SPH 2007a)
- Evaluation of Separate-Phase Hydrocarbons – July 2007: Asphalt Plant Area, Client/Site Confidential. Prepared August 24, 2007. (SPH 2007b)

It is important to note that there are likely a significant amount of data pertaining to the property's hydraulic properties that have been collected and reported during the course of remedial investigation activities at the property; however, due to developing project familiarity and inherent cost associated with the re-evaluation of historical data and the constraints placed upon this report, what is believed to be a relatively small portion of property data were used in reference for this project.

The aforementioned reports for the property were assessed on the assumption that the data was collected using methods that were applicable industry standards for the time of that study, and that any calculations completed within the reports were completed correctly since most raw data is unavailable. Based on these assumptions, the historical property studies were reviewed and evaluated for information pertinent to the evaluation of groundwater flow proximate to the seawall (within 50 feet or less). Upon completion of reviewing the historical studies of the property's hydrologic conditions/values, the usable information gathered was referenced in the preparation of the proposed additional study.

4.2 HYDRAULIC BALANCE

The hydraulic balance completed for the property was completed through the collection, interpretation, and calculation of various data that are representative of conditions at the property. After all pertinent variables were identified with applicable values, a series of calculations were applied in order to obtain a final output (positive or negative) of hydraulic activity for the property. The goal for the output was to calculate the minimum amount of water introduced into the property's subsurface through precipitation. The data collected, interpreted, and calculated are identified and described in further detail as follows:

- **Hydraulic Balance Area –** This is the portion of the property being evaluated for the purposes of this hydraulic balance. The portion of the property being evaluated totals approximately 45 acres (approximately 2,041,200 square-feet). This variable is estimated to have a relatively low margin for error based upon measurements of the property.

- **Precipitation –** Precipitation data was gathered from online sources from a local rain gauge. The precipitation data for the property yielded an precipitation total for the property of approximately 48.5 inches for the year of 2014 (SMP 2015). This variable presents a minimal margin for error from instrumentation due to the data recording source. The data for the purposes of this calculation were measured; however, the values of the final calculations could vary greatly depending upon the year in which precipitation data is referenced. Depending upon the year, precipitation could vary by up to 10 inches, and would account for a calculated variance of ± 20% (approximately 12,000,000 gallons of water annually).

- **Up-Gradient Sources –** The property does not reportedly receive an input of water from the up-gradient glacially deposited bluff due to a network of diversion channels and culverts at, and adjacent to, the property. Although it is reasonable to believe that the property will receive some amount of hydraulic input from the up-gradient bluff, studies have not been completed to accurately quantify recharge capabilities of the adjacent bluff. Due to the absence of accurate recharge data from the adjacent bluff as well as the goal to calculate a minimum amount of water introduced into the property's subsurface; up-gradient sources were not included within the calculation of the hydraulic balance. This variable presents an unknown margin of error for the calculation of the hydraulic balance at the property; however, without representative data for up-gradient sources, it would not be responsible to speculate on the influence this additional source may or may not have on the property without first gathering these data. Since we cannot speculate as to this influence, this variable is considered to be a data gap.

- **Site Permeability –** Permeability at the property was estimated by visual inspection of pervious areas of the property. Portions of the property are paved, and these areas direct precipitation into storm water drains located throughout the property or onto permeable surfaces. Given the assumption that all storm water conveyance systems are in good working order (not leaking), then an estimated 50% of precipitation that falls upon the property will not contribute to groundwater recharge at the property. The remaining 50% of precipitation that falls on the property is then assumed to become located at pervious areas of the property. This variable presents a moderate margin for error due to its estimation through visual inspection and conversations with the project manager at SLR. Since the permeable area at the property has not been properly surveyed, it is possible this value can vary by 10% to 15%.

- **Transpiration –** Although the property contains many pervious areas, the property does not have much vegetation. In general, vegetation at the property includes low lying grasses and small bushes. Due to the minimal amount of vegetation at the property, the effects of water loss due to transpiration are negligible and were not included within the calculation of the hydraulic balance for the property. This variable presents a very low margin for error due to the extreme lack of vegetation at the property.

- **Evaporation –** Evaporation data was gathered from an online source that provided average pan evaporation data for the Seattle area for the years 1941-1960. The data reviewed presented an average evaporation rate of 34.52 inches of precipitation per year (Evaporation 2015). The data collected for evaporation was then used in conjunction with the reviewed precipitation data to calculate a potential evaporation rate of approximately 71%. It is important to note that this number represents the potential evaporation, and not the actual evaporation at the property. It is entirely possible that as little as 20% of precipitation which falls onto permeable portions of the property will actually evaporate. In this case, an evaporation rate this low (20%) would allow for an approximate addition of water to the property on an annual basis of almost 16,000,000 gallons when compared to the value calculated at an evaporation rate of 71%.

- **Property Pump-and-Treat Operations –** The water treatment system on the property pumps from five wells located at three areas of the property each pumping at 1 gpm. The water is subsequently treated and discharged into the adjacent body of water effectively removing approximately 7,200 gallons of groundwater per day (approximately 2,628,000 gallons per year). This variable has a relatively low margin for error since the pumps are calibrated on a weekly basis. Certain pumps may be shut down for a short period of time for maintenance purposes (several hours); however, the affect these shutdowns have on the calculated flow is negligible.

The calculations for the hydraulic budget were completed using the property's hydraulic inputs (precipitation), and its hydraulic outputs or limiting factors (permeability, evaporation, and system pumping operations). The following (re-worked) rudimentary water balance equation was used in the evaluation of the hydraulic balance for the property:

Inflow ± Changes in Storage = Outflow (Fetter pg.8)

This equation was further developed for the purposes of this hydraulic balance to account for the order in which water enters and/or exits the hydraulic balance area. The inflow for the property is essentially a change in storage for the purposes of this hydraulic balance: precipitation. Since approximately 50% of the site is pervious, only half of the precipitation was included when addressing further changes in storage. Evaporation (a potential of 71%) was then taken into account prior to evaluating the influence of the property's water pumping and treatment system, and a final hydraulic output was calculated for the property.

The calculated hydraulic balance will suffice for a general knowledge of whether or not excess water is introduced to the subsurface of the property, or if pumping operations and evaporation will diminish the excess water introduced into the property's subsurface. It is important to note that prior to this project, a hydraulic balance had not been evaluated for the property.

4.3 DEVELOP ADDITIONAL STUDY

Since the previous tidal study was completed in a segmented format of three separate 72-hour studies with a focus to evaluate potential contaminant flow about the property within the bounds of the seawall, the findings of the previous study are limited in their ability to provide useful information for the purposes of migration through the seawall with the exception of occasional hydraulic conductivity data. The data included within the tables and figures of the previous studies enable the calculation of transmissivity and storativity for select monitoring points at the property; however, the amount of useful data yielded will need to be expanded in an effort to better understand flow through or around the seawall. Transmissivity data will be extremely useful since it represents the amount of water that can be transmitted horizontally through a unit width by the full saturated thickness of the aquifer; transmissivity for wells with available hydraulic conductivity values was calculated using:

$T = bK$ (Fetter pg.100)

Where T is the transmissivity, K is the hydraulic conductivity, and b is the saturated thickness of the aquifer. Values for storativity are needed to complete other calculations such as tidal lag (time between peak high tide and peak water level) and tidal efficiency (the ratio of fluctuation between the potentiometric surface changes within the aquifer to the actual tidal fluctuation). Tidal lag can help visualize the propagation of groundwater through time across monitoring points relative to one another, and tidal efficiency provides a well's propensity to fluctuate with the rising and falling tides. Since the data used in the previous study calculations were not made available, the time lag equation (Fetter pg.338) was solved for storativity:

$$S = \frac{\left(\frac{t_\tau}{x}\right)^2 4\pi T}{t_0}$$

Where t_τ is the calculated time lag at that location, x is the horizontal distance from the shoreline, and t_0 is the time it takes in between tidal extremes (typically 12 hours). Being able to solve storativity from the data that has already been collected is important because there are currently no recorded values for porosity, aquifer compressibility, or the specific yield of the aquifer which are typically used to calculate storativity specific to an aquifer. There is only one well proximate to the seawall which contains sufficient data (tidal lag and hydraulic conductivity) to calculate storativity in the equation presented above: AP-10. Since this value will be the only available, the storativity calculated for AP-10 will be used for wells located proximate to the seawall for the purposes of this report.

Due to the desires of the client and SLR, a single simultaneous tidal study will be proposed along the entirety of the seawall in an effort to observe the propagation of flow through or around the seawall as a function of the rise and fall of water levels within monitoring points (wells) relative to one another. Although it may be possible to identify potential preferential pathways along the seawall through the interpretation of previously collected data; the time, resources, and potential data gaps are too large of a risk when compared to the known cost of the proposed additional tidal study at the property. This additional study is proposed based upon:

- The need for additional calculated aquifer characteristics (i.e. transmissivity, tidal lag, and tidal efficiency); and

- The ability to observe actual flow propagation at and proximate to the seawall in two-dimensions through time without the need to piece separate studies together.

In an effort to minimize duplicate data, the wells that were used during the previous historical investigations will not be used as monitoring points during the proposed additional study. This way, the maximum amount of new data can be collected while being able to use the previous data (such as hydraulic conductivities) for supplementary purposes. The details of how the proposed tidal study will be conducted are described in section 5.3.

5.0 RESULTS AND DISCUSSION

The following sections and subsections provide the findings resultant from the aforementioned activities conducted for the purposes of this report. This section will present the results and findings with discussion as needed; leaving conclusions and recommendations to the following section (§6.0) of the report.

5.1 HISTORICAL STUDY REVIEW

The following sub-sections present the results of the historical review as it pertains to the noted individual documents. Due to the confidentiality of the property, the reports will not be made available in their entirety; however, if specific information is needed for review or confirmation purposes, specific portions of the document of interest may be requested for review upon concealing client and property identity prior to the delivery of the requested documents.

5.1.1 2005 Groundwater Investigations (GI 2006)

This document contained three individual 72-hour tidal studies for the property (north, central, and south) and hydraulic conductivity testing for the property at select locations by way of slug testing.

5.1.1.1 Tidal Survey

The tidal study completed in 2005 at the property was intended to assist in the understanding of the hydraulic conditions across the property within the bounds of the seawall. The property was divided into three segments in which independent tidal studies were completed that were then evaluated as a whole. The three sections and wells observed during the study are presented as follows:

- Northern portion: AP-11, AP-38, AP-8, AP-9, AP-10, AP-16, AP-26, AP-21, AP-13, and AP-14.

- Central portion: MW-54, MW-1, MW-3, MW-15, MW-14, MW-35, MW-73, MW-36, and MW-39.

- Southern portion: MW-8, MW-102, MW-84, MW-56, MW-83, MW-65, MW-10B, MW-67, M-631, and MW-101.

A figure depicting the three divided sections and wells used during the 2005 tidal study is provided as Figure 3.

The three sections of the property were individually monitored over a 72-hour period to assess the influence that tidal effects have on groundwater at the property. Tidal lag and tidal efficiency were calculated at select wells in order to assess how and where the tidal fluctuations impact the groundwater at the property. Tidal influence was measured through water level measurements within the individual wells using transducers. This report did not specify the reasons for the monitoring location placement or well selection, or why the tidal study was segmented into three sections the way it was. Additional data, aside from elevation data, were not collected from the wells during the course of the tidal study.

The northern section of the study recorded water levels ranging from 2.07 (AP-10) to 5.30 (AP-

16) feet relative to the North American Vertical Datum of 1988 (NAVD88) and an average mean elevation of 3.38 feet NAVD88. Water level measurements during the study at the northern portion of the property indicate a down-gradient flow toward the large tidally influenced body of water. Tidal efficiency for the northern portion of the property ranged from 2% (AP-16) to 42% (AP-10), and tidal lag measured between 60 and 102 minutes. In general, tidal efficiency decreased with increased distance from the shoreline. A figure depicting the tidal graphs for individual wells in the northern portion of the property are presented as Figure 4.

The central section of the study recorded water levels ranging from 0.82 (MW-54) to 7.26 (MW-3) feet NAVD88 and an average mean elevation of 3.94 feet NAVD88. Water level measurements during the study at the central portion of the property indicate a down-gradient flow toward the large tidally influenced body of water. Tidal efficiency for the central portion of the property ranged from 1% (MW-15 and MW-35) to 42% (MW-39), and tidal lag measured between 93 and 125 minutes. In general, tidal efficiency decreased with increased distance from the shoreline with the exception of MW-14, which had a tidal efficiency greater than several wells that were more closely located to the shoreline. A figure depicting the tidal graphs for individual wells in the central portion of the property are presented as Figure 5.

The southern section of the study recorded water levels ranging from 2.79 (M-631) to 7.28 (MW-101) feet NAVD88 and an average mean elevation of 5.22 feet NAVD88. Water level measurements during the study at the southern portion of the property do not indicate a clear direction for shallow subsurface flow. Tidal efficiency for the southern portion of the property ranged from 0% (MW-83) to 70% (M-631). Only tidal lag for M-631 was calculated; the tidal lag averaged 26 minutes. Most of the wells located in the southern portion of the property were not influenced by tidal effects relative to other portions of the property. M-631 recorded the highest tidal efficiency for the property; however, M-631 was reportedly completed to a depth of greater than 30 bgs, locating the well within an apparent deeper water-bearing zone of the property. A figure depicting the tidal graphs for individual wells in the southern portion of the property is presented as Figure 6. Table 1 provides data extracted from this tidal study, as well as additional transmissivity values calculated for this report.

5.1.1.2 Hydraulic Conductivity Testing

Hydraulic conductivity testing was conducted in 17 wells located at select areas of the property. The testing was completed by using the “slug” test method and using either the Bouwer and Rice method (Bouwer and Rice 1976, Bouwer 1989) or the Butler and Garnett method (Butler and Garnett 2000). The only well which hydraulic conductivity was calculated using the Butler Garnett method was well M-631.

Well M-631 was observed to have an oscillatory response due to the apparent relatively high hydraulic conductivity at that location. The oscillatory responses suggest a hydraulic conductivity of greater than 10^{-1} cm/sec. The remaining wells resulted in calculated hydraulic conductivities ranging from 1.70×10^{-3} to 5.30×10^{-2} cm/sec, with an average value of 1.10×10^{-2} cm/sec. Table 2 provides data extracted from the hydraulic conductivity testing, as well as additional transmissivity values calculated for this report.

The results of the slug testing reinforce the concept of heterogeneity within shallow groundwater flow in the anthropogenic fill. The differences in hydraulic conductivity can infer compaction differences during construction; material differences across a section of the property used for fill; or potential historical structures, foundations, or infrastructure which were not historically documented and are locally diverting groundwater flow. Although the limited data presented cannot be used to create a useful model for the purposes of the client for a sediment sampling plan, the data available can still be used for supplementary purposes during the evaluation of data collected during the proposed additional study. The varied nature of the seawall is known; however the goal is to find what can potentially be a relatively small pathway when compared to the extent of the seawall, and any additional information that may assist in closing data gaps will be useful without providing additional cost to the project.

5.1.2 Potential SPH Migration (SPH 2006)

The purpose of this document was to report the techniques applied to the property in order to effectively mitigate the potential for SPH to migrate off of the property into sediments at the northern portion of the property.

A sheet pile containment wall was installed at the northern portion of the property in 1999 spanning approximately 224 linear feet along the shoreline and driven to a depth of approximately 25 feet bgs. The installation of the sheet pile wall was implemented due to known SPH migration at that portion of the property. Additionally, this study specifies that approximately 30 wells located in the northern portion of the property do not have properly surveyed top of casing (TOC) elevations. The lack of surveyed casing elevations will need to be considered when selecting monitoring locations for the proposed additional study.

Due the required installation of the sheet pile wall along the northern portion of the property to mitigate the migration of contaminants, it is evident that hydraulic activity at the property is capable of transporting contaminants off of the property, therefore reinforcing the need to identify additional preferential pathways.

5.1.3 Evaluation of Separate-Phase Hydrocarbons (SPH 2007a)

The purpose of this study was to evaluate the current state of SPH at the northern portion of the property during the time of evaluation. Measureable amounts of SPH were observed in wells adjacent to the northern and southern limits of the aforementioned sheet pile containment wall; however, this study determined that the data do not definitively identify whether or not SPH was migrating off of the property after the installation of the sheet-pile wall. Groundwater was measured at the property ranging from 1 to 4 feet elevation relative to NAVD88.

Groundwater levels measured during high/high and low/low tidal conditions indicate a down-gradient flow of groundwater toward a “sink” behind the sheet pile wall during high tide conditions, and a mounding effect of groundwater behind the sheet pile wall during times of low tide, producing a down-gradient flow off of the property. The observed “sink” and “mound” conditions at the sheet pile wall indicate a hydraulic connection between the tidally influenced body of water and the groundwater at the property.

5.1.4 Evaluation of Separate-Phase Hydrocarbons (SPH 2007b)

The purpose of this study was to provide additional evaluation of the state of SPH at the northern portion of the property after the installation of the sheet-pile wall. Groundwater was measured at the property ranging from 1 to 4 feet elevation relative to NAVD88. Groundwater levels measured during high/high and low/low tidal conditions indicate a down-gradient flow of groundwater toward a “sink” behind the sheet pile wall during high tide conditions, and a mounding effect of groundwater behind the sheet pile wall during times of low tide, producing a down-gradient flow off of the property. No additional findings resulted from this study relative to the aforementioned SPH study (SPH 2007a).

5.1.5 Historical Study Inclusion

The storativity used for calculations of transmissivity in wells along the seawall was derived from well AP-10 (as mentioned in §4.3), yielding a value of 0.053. This value of storativity was used in any applicable calculation relating to wells proximate to the seawall since porosity, skeletal compressibility, and specific yield data were not available. After reviewing the data of the previous tidal study and hydraulic conductivity testing, transmissivity values were calculated where applicable. Unfortunately, the tidal efficiency within the historical study was calculated as follows:

$$Tidal\ Efficiency = \frac{\Delta h_w}{\Delta h_t} \times 100$$

Where Δh_w is the maximum potentiometric surface fluctuation within the well and Δh_t is fluctuation between tidal extremes. With raw data unavailable for additional calculation, transmissivity could not be calculated at the well locations in which only tidal efficacy was calculated; however, transmissivity was calculated for wells in which tidal lag data were available by again rearranging the tidal lag formula (Fetter pg. 338) to solve for transmissivity:

$$T = \frac{t_0 S}{\left(\frac{t_\tau}{x}\right)^2 4\pi}$$

This equation enables the use of the previously calculated storativity of a well along the seawall in conjunction with the associated tidal lag to produce a transmissivity for the given well. Of the wells included within this study, only five wells were able to have calculated transmissivity values and were proximate to the seawall. The five wells proximate to the seawall had values of transmissivity ranging from 231 to 5,349 ft^2/day (MW-39 and M-631 respectively). The highest transmissivity can be attributed to M-631 being screened within a deeper water-bearing zone on the southern portion of the property, leaving shallow aquifer transmissivity values ranging from 231 to 1,009 ft^2/day (MW-39 and AP-38 respectively) with an average transmissivity of 508 ft^2/day within the shallow water-bearing zone.

Salinity data was not recorded during the course of any of the studies reviewed. Typically, the interface between fresh-water and salt-water has a steep gradient as represented by the Dupuit-Ghyden-Herzberg model (Fetter pg.334):

$$z = \sqrt{\frac{2q'xG}{K}} \qquad where\ G = \frac{\rho_w}{\rho_s - \rho_w}$$

Where z is the depth to the fresh/salt water interface, q' is the discharge per unit width, K is the hydraulic conductivity, x is the distance from the shoreline, and ρ_w and ρ_s are the density of the fresh-water and salt-water respectively. Generally, the depth to the fresh/salt water interface is approximately 40 times that of the aquifer's saturated thickness above sea level. Using this concept, the depth in which great salinity fluctuation should be observed across the property (groundwater at approximately 2 to 7 feet NAVD88) is anywhere from 80 to 280 feet bgs. Therefore, great salinity fluctuations in the monitoring locations should not be expected unless there is a direct pathway through the seawall for saltwater to interact with the bounded area of property during high tide conditions. If seeps are present within relatively higher locations along the seawall (above the water table on the property), then some amount of salt-water will be able to migrate onto the property during high tide conditions, and exit the property at the same location during low tide conditions, potentially bringing contaminants with it. Because potentially higher seeps within the seawall could be present, measurements of salinity should be collected (if possible) during the tidal study to evaluate the potential for salt-water intrusion along the seawall. In the unexpected event that great salinity fluctuations are observed in numerous monitoring locations, the salinity concentrations through time can be thought of as a tracer to evaluate the propagation of flow throughout the property during high and low tide conditions by comparing salinity concentrations at monitoring points relative to one another.

5.2 HYDRAULIC BALANCE

The hydraulic balance calculated for the property indicated a surplus of water was being introduced to the property throughout the course of the year (2014). After accounting for precipitation, and its loss due to impervious surfaces at the property, evaporation, and pumping operations at the property, the hydraulic balance for the property yielded a surplus of approximately 526,000 gallons per month (approximately 6,300,000 gallons per year). Since the goal of the hydraulic balance was to identify a potential minimum amount of recharge to groundwater at the property, actual numbers for water surplus could potentially increase by a factor of five to ten. Calculations for the hydraulic balance are provided in detail in Table 3.

Given the results of the hydraulic balance, there is a known surplus of water at the property that is not extracted during pumping operations or dissipating through evaporation. The hydraulic balance indicates that an average of approximately 500,000 gallons of water is added to the property every month; however, the actual amount is most-likely greater due to the value of potential evaporation (71%) used during the hydraulic balance calculation. This value could potentially be much higher with adjustments to the variables (potential error) as described above. To achieve a groundwater equilibrium at the property (water is not overflowing at the property), the surplus of water must travel somewhere preferentially, and potentially bring contaminants along with it. Historical studies have shown that portions of the property are influenced by tidal fluctuations and have the ability to transport contaminants off of the property, therefore it is more probable than not that additional preferential pathways are present along the seawall.

5.3 PROPOSED ADDITIONAL STUDY

A tidal study will be completed over a 72-hour period to observe the propagation of flow through and around the seawall relative to discrete monitoring points, as well as gather raw data to calculate additional transmissivity values along the seawall. The observation of propagating flow through and along the seawall in conjunction with additional transmissivity data will hopefully provide the necessary tools to identify potential pathways along the seawall. This proposed study will be completed as a single simultaneous tidal study along the seawall in its entirety. The proposed tidal study will consist of approximately 15 monitoring points (wells already installed at the property) located east of the seawall within 50 feet of the shoreline. In order to gather data for groundwater elevations in conjunction with potential saltwater intrusion, multi-parameter transducers capable of recording water level and salinity will be placed at the select 15 monitoring locations.

Of the 15 monitoring wells, 12 wells will be screened within the shallow groundwater zone (approximately 10 to 15 feet bgs), and three will be screened within the potential deeper groundwater zone (approximately 20 to 30 feet bgs). The deeper monitoring locations will be paired adjacent to a shallow zone well concurrently monitored during this study. The 12 shallow monitoring locations will be spread at approximately 250-foot intervals along the 3,200-foot seawall, and the three deeper monitoring points will be placed in the northern, central, and southern portions of the property paired with an applicable shallow monitoring point used during this tidal study. Additionally, one stilling well will be installed alongside the dock connected to the property on the west-adjacent tidally influenced body of water to measure the actual tidal elevations within the body of water as a reference to the 15 monitoring points located on the property. Since there is no expected salinity fluctuations at the stilling well, a transducer solely capable of recording water levels will be used at that location. The stilling well will be installed at the dock prior to any of the transducers being placed for recording, and the stilling well's elevation will be surveyed relative to the NAVD88. Once the stilling well is installed the 15 multi-parameter and one stilling well transducer will record measurable data once every 5 minutes over the 72-hour tidal study period. Water levels will be manually recorded a minimum of five times per 24-hour period over the 72-hour study with an oil/water interface probe. Although not anticipated, any measurable amounts of petroleum hydrocarbons identified within the monitoring points shall be recorded along with the water level at the given well. Measurements of the product thickness (if encountered) could be useful in evaluating the product's mobility based upon the fluctuations of thickness over the course of the tidal study.

The 72-hour period will not begin until the final transducer is placed. Subsequently, the study period will terminate upon the removal of the first transducer to allow each monitoring point a complete 72-hour study period. The transducers will be linked to an appropriate data logger upon completion of the study and data will be placed onto a working digital spreadsheet. Upon the completion of the tidal study the data will be visually inspected by producing time-lapse imagery through fence diagrams and plan view, as well as calculate transmissivity values for the new monitoring locations. The transmissivity for the new monitoring locations will be calculated using the equation for the amplitude of tidal fluctuation (Fetter pg.337) as solved for transmissivity:

$$T = \frac{\pi S}{t_0 \left[\frac{\left(\frac{\ln h_x}{\ln h_0} \right)}{-x} \right]^2}$$

Where h_x is the amplitude of tidal fluctuation within the well and h_0 is the amplitude in tidal change. Hopefully, once transmissivity values are calculated for the new monitoring locations, subsurface flow along the seawall can be interpreted or modeled based upon areas of greater transmissivity and/or areas in which tidal fluctuations were notably larger. There is a distinct possibility that due to the spacing of the monitoring locations for the proposed study, preferential pathways may be “lost” within the results due to their scale relative to the distance between monitoring points. However, the hope is that the 12 monitoring points (creating 13 smaller 250-foot study areas) will effectively narrow down the areas of interest to a smaller scale when compared to the property. This potential for error will be evaluated further after the completion of the proposed study, and during the development of the sediment sampling plan.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Due to the property's size and permeability, a notable amount of water is introduced into the subsurface after every precipitation event. Although evaporation and pumping activities lessen the amount of water that is introduced into the property's subsurface, they do not create a groundwater equilibrium at the property. The sheet pile containment wall and associated study at the northern portion of the property show that, although the sheet pile wall appears to limit tidal influence at its point of installation, the areas on either side of the sheet pile wall appear to be greatly influenced by the tidal fluctuations. An estimated minimum surplus of over 500,000 gallons of water per month (approximately 12.02 gallons per minute) in conjunction with the ability for the property's groundwater to interact with tidal fluctuation indicates that groundwater must leave the property at some location every month in order to maintain the shallow groundwater conditions that are present. Had the hydraulic balance yielded a much lower surplus or even a deficit of water at the property (due to pumping activities and evaporation), a simplified sediment sampling plan could be proposed due to the unlikely possibility of contaminants travelling beyond the seawall. However, the need for a sheet pile wall to be installed, tidal interaction evident around the sheet pile wall, and the hydraulic balance calculated for the property suggests the need for additional information along the property's seawall since it is more probable than not that contaminants have, and potentially still are, migrating beyond the seawall into adjacent shoreline sediments.

The historical tidal study and hydraulic conductivity testing yielded some transmissivity values for the property, as well as provide an insight into the potential for a deeper aquifer at portions of the property. Unfortunately, this data alone will not suffice to identify potential pathways along the seawall to the scale that is desired by the client. Minimal data was available for interpretation, and any calculations within this study had to be derived from calculated values from the previous tidal study, or values that could be obtained by other means. The transmissivity values resultant from the historical study will serve as supplementary data to the proposed tidal study, and if pertinent raw data from the historical studies become available at some point, then a re-evaluation of the material may be conducted if needed.

Potential pathways along the seawall are of unknown size and location, making it difficult to decide the final monitoring locations. The proposed locations of the transducers are due to a mixture of variables which include, budget, instrument availability, and the conditions of the wells at the property. The final locations of the proposed tidal study are not in place due to the additional well elevation surveying and inspection of well integrity that need to be completed prior to the tidal study. Since these limitations for the study are present, the proposed additional study was developed with what is believed to be the most efficient methodology to best address the objective of identifying preferential pathways along the seawall.

The deeper transducers in the proposed additional study are intended to identify the potential for multiple groundwater zones along the property. The identification of potential multiple aquifers can be done by comparing values of the paired deep and shallow wells relative to one another such as tidal efficiency, tidal lag, transmissivity, or salinity concentrations. The southern portion of the property displayed an average tidal efficiency within the shallow wells of less than 5 percent; however, the deeper well used within the historical tidal study recorded a tidal efficiency of over 70 percent, inferring a near direct correlation to tidal fluctuations. This differentiation between deep and shallow zones on the southern portion of the property can be attributed to the historical salt marsh deposits in that area of the property. Due to these findings, it is important to identify the potential for multiple groundwater zones across the property since multiple zones have already been identified at one portion of the property. Multiple water-bearing zones at the property could help keep the contaminants from migrating off of the property since contaminants are most likely constrained to the shallow zone as light non-aqueous phase liquid. If a deeper aquifer exists, it is possible a large portion of the recharge at the property from precipitation migrates beneath the seawall rather than through or around it, leaving the gross contaminants essentially stagnant within the bounds of the seawall. The potential for water to migrate beneath the seawall would, however, require the seawall's construction to be sound and to depths in which the gross non-aqueous contaminants could not migrate (similar to the sheet-pile wall), making this scenario unlikely for the entire seawall.

This report has identified the need for additional data that can be collected through available avenues for the property based upon the client's desires and project needs. The proposed additional study will provide the necessary data to calculate additional aquifer characteristics for the property along the seawall, as well as provide the ability to observe actual flow propagation proximate to the seawall in two-dimensions through time during a single simultaneous event. Ultimately, the proposed additional study is suggested based upon its relatively low capital investment, and ability meet the needs relevant to the specific project needs and scope. Assuming preferential pathways are identified through the additional study proposed within this report, a representative and cost-effective sediment sampling plan can then be put in place in an effort to define the site.

7.0 REFERENCES

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8.0 STATEMENT OF LIMITATIONS

The conclusions and recommendations contained in this study are based upon opinions with regard to the subject matter. These opinions have been arrived at in accordance with currently accepted practices applicable, and are subject to the following inherent limitations:

Accuracy of Information - Certain information used in this study has been obtained, reviewed, and evaluated from various sources believed to be reliable. This study has based its conclusions, opinions, and recommendations in part on such information; however, this study did not include the verification of the accuracy or authenticity of such information. Should such information prove to be inaccurate or unreliable, this study shall be amended or revised to appropriately update its conclusions, opinions, and/or recommendations.

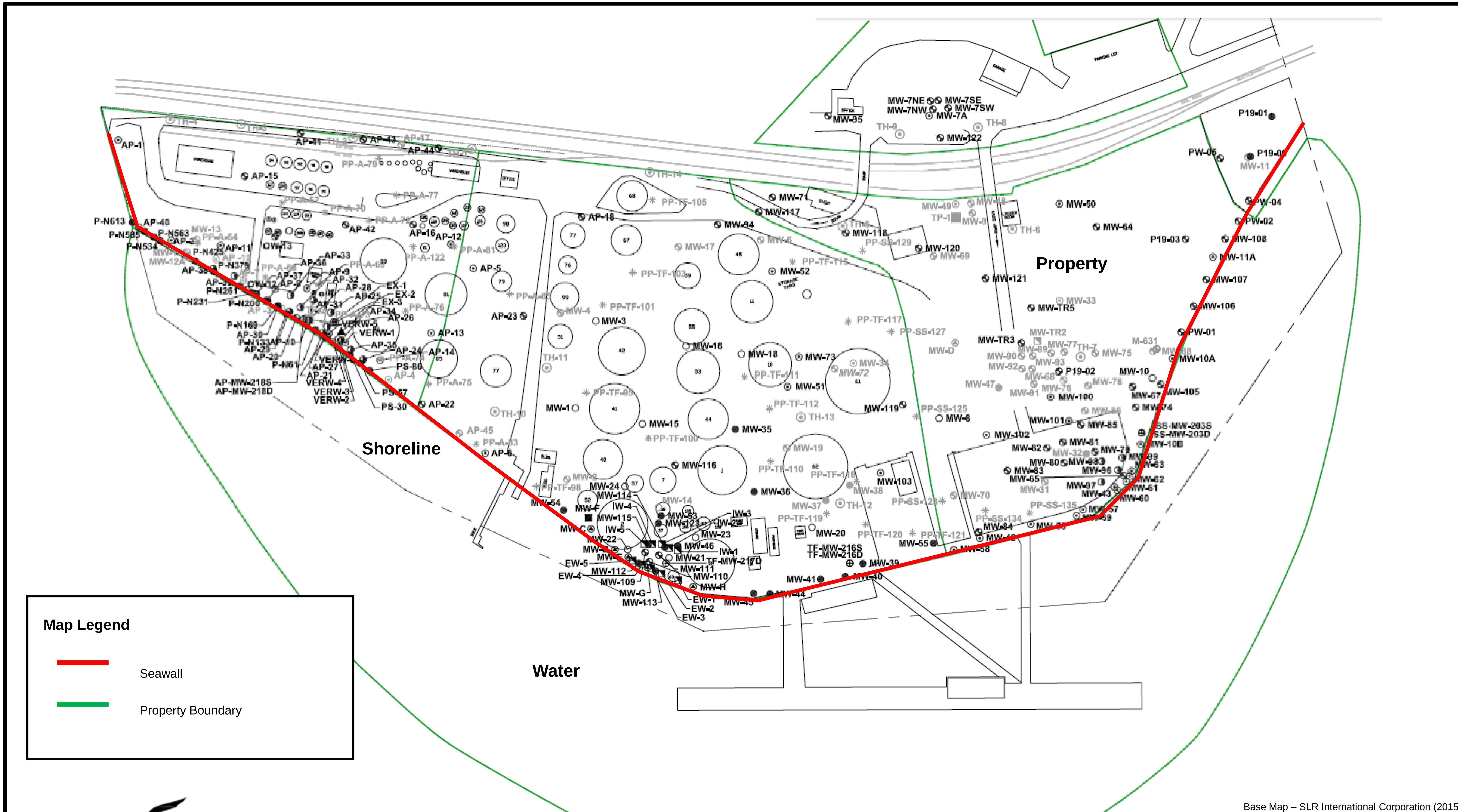
Limitations - This report/assessment has been prepared in accordance with the University of Washington Capstone criteria and currently accepted industry standards, and no other warranties, representations, or certifications are made. This study is intended for and restricted to the sole use of the University of Washington MESSAGe program. Any use, interpretation, or reliance upon this study by anyone other than the University of Washington is at the sole risk of that party, and this study shall have no liability for such unauthorized use, interpretation, or reliance.

FIGURES

CAPSTONE PROJECT

PETER LEDOUX
UNIVERSITY OF WASHINGTON
SEATTLE, WASHINGTON

MESSAGe Technical Report Number: 023



Base Map – SLR International Corporation (2015)

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MESSAGe Capstone Project - 2015
Figure 1
Site Plan

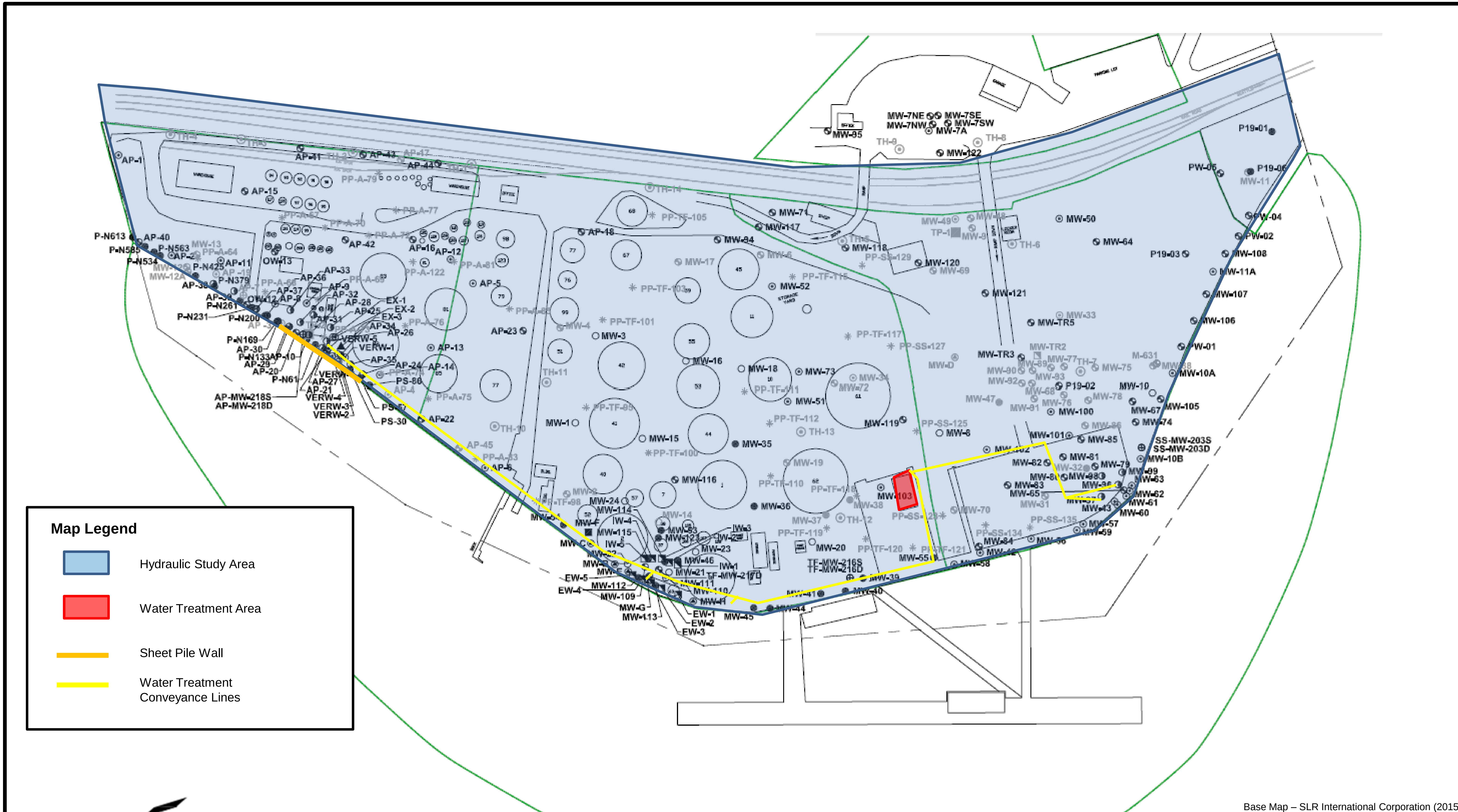

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Figure 2
Property Features Map

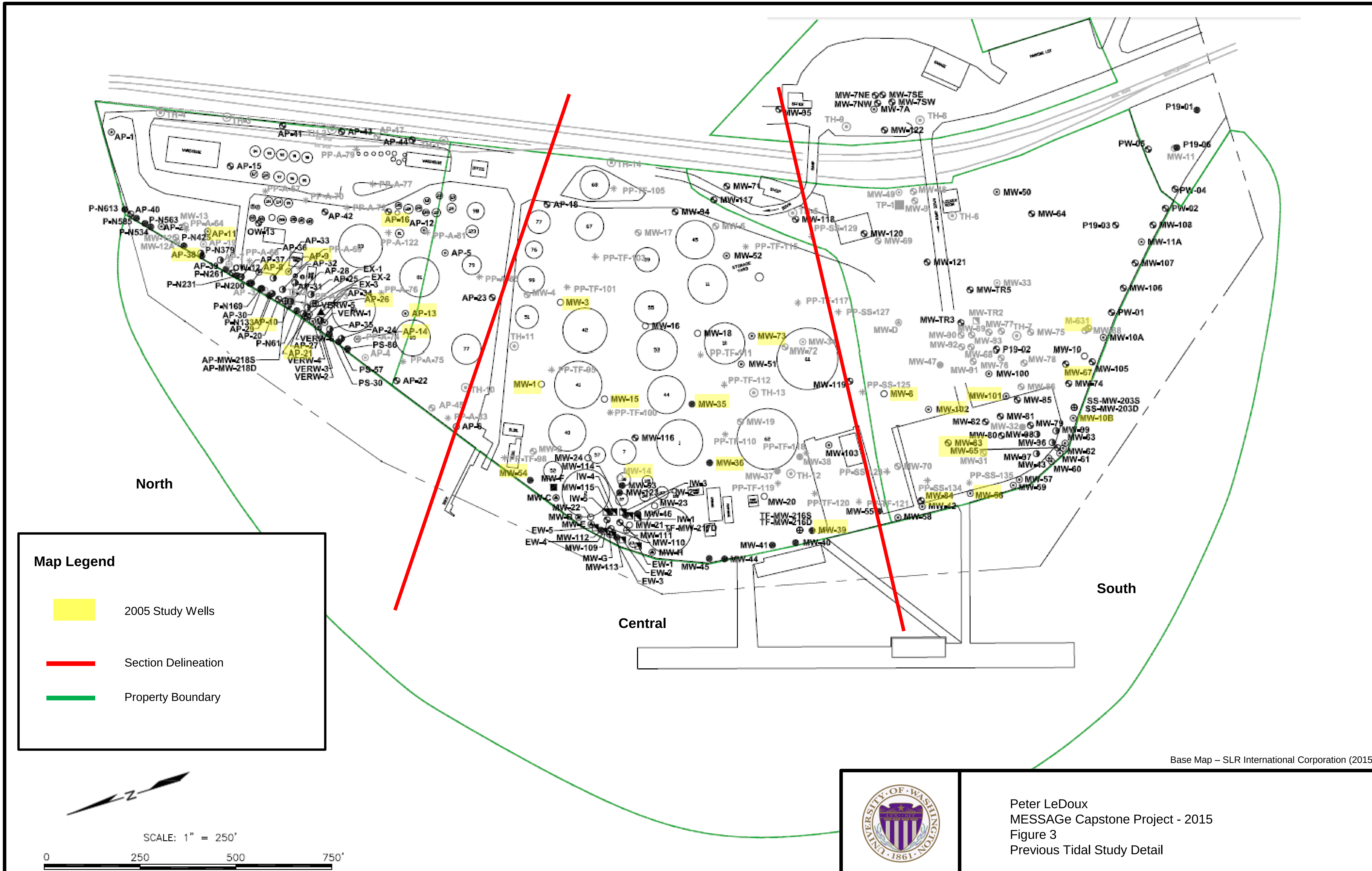

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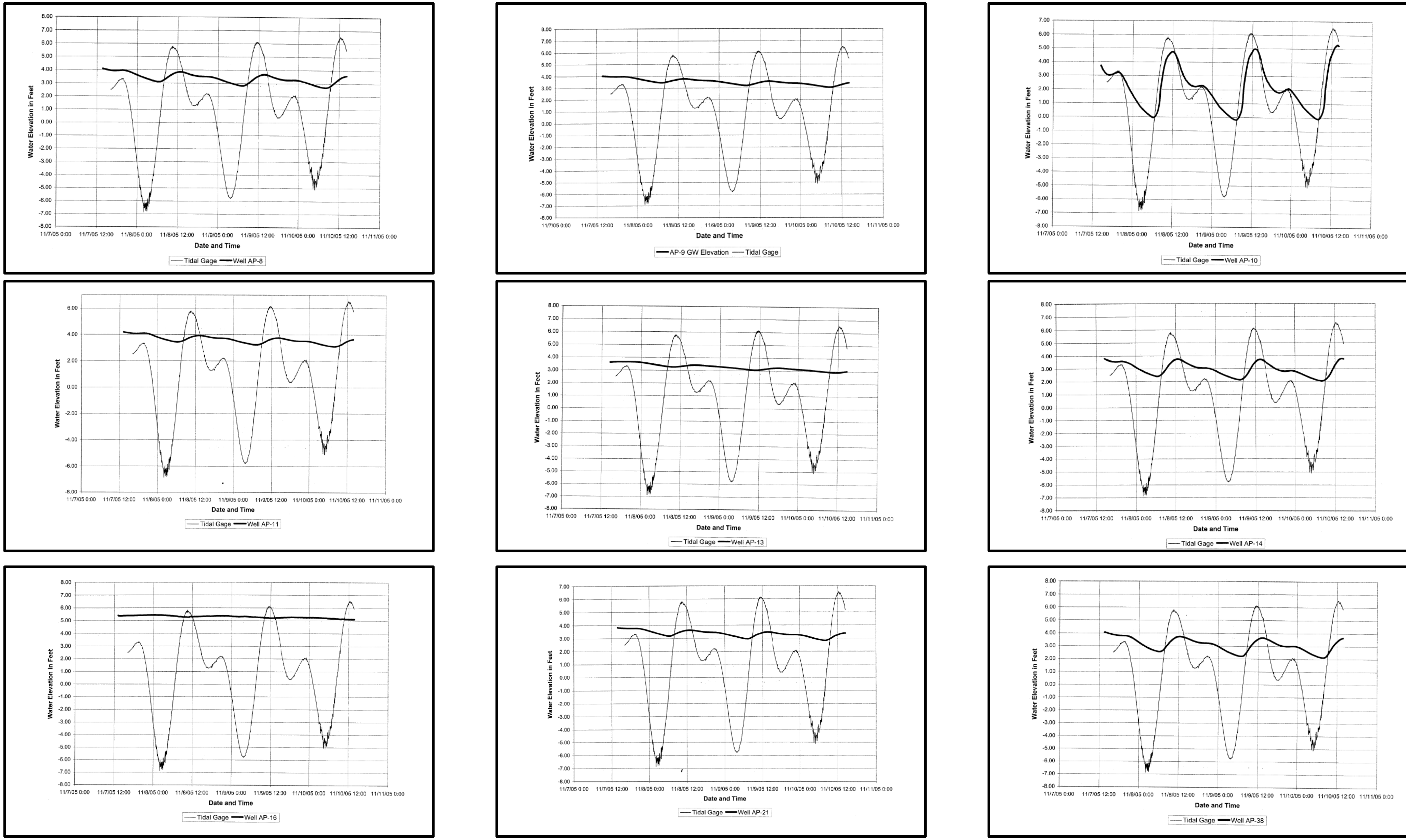
Figure 3
Previous Tidal Study Detail



Tidal Graphs – 2005 Groundwater Investigations (2006)

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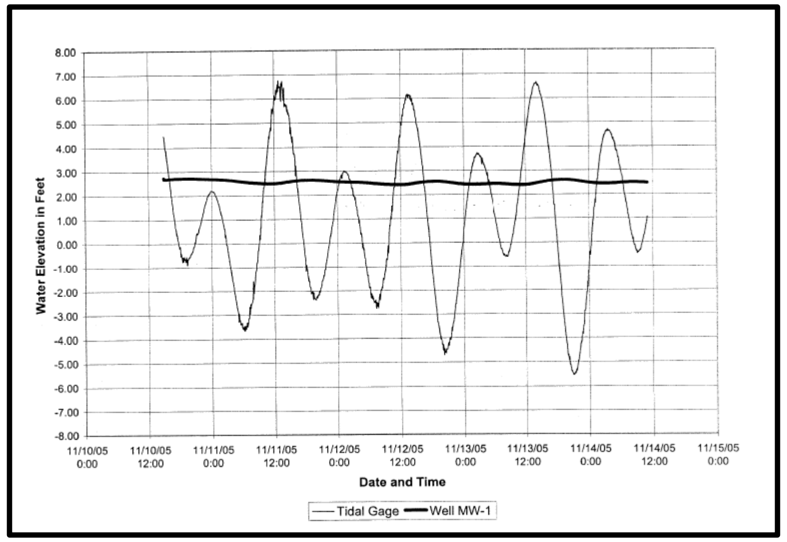
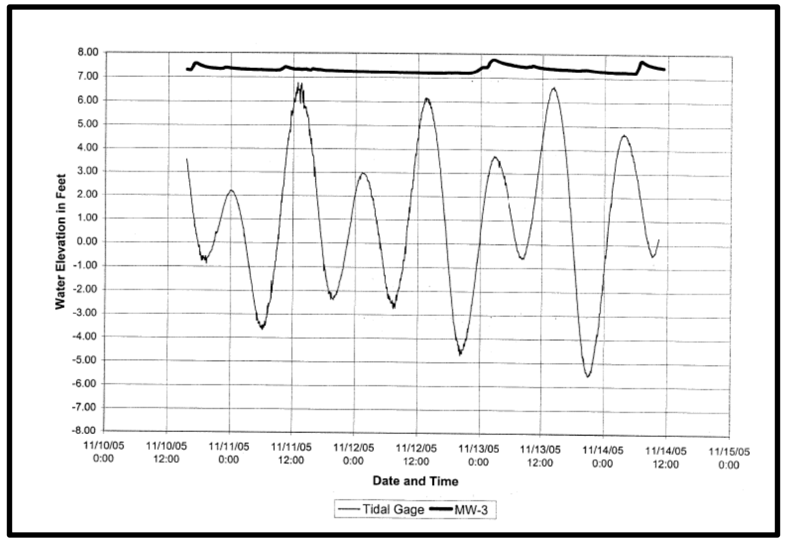
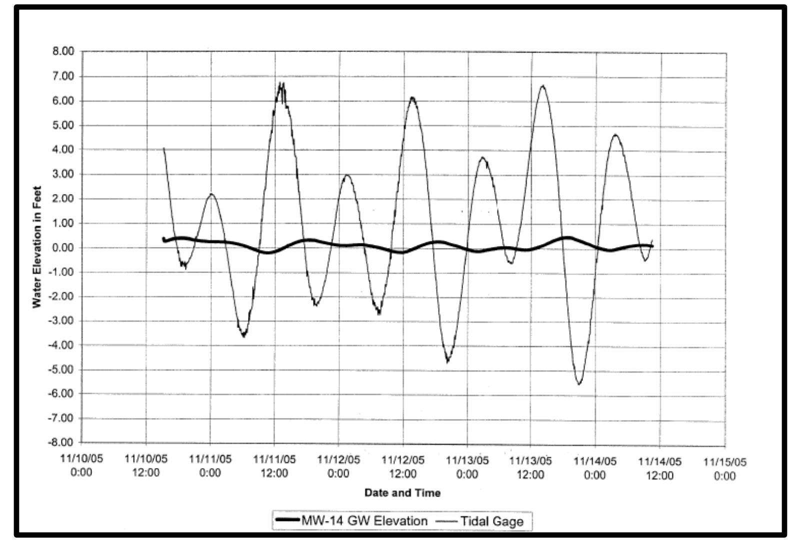
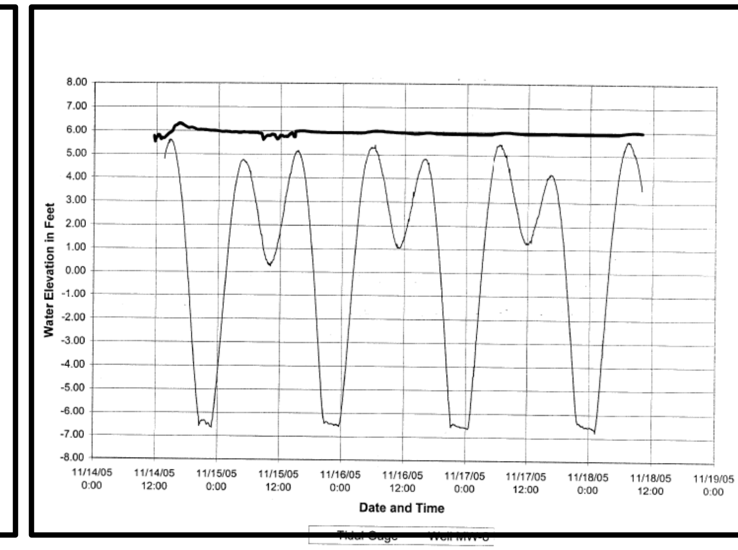
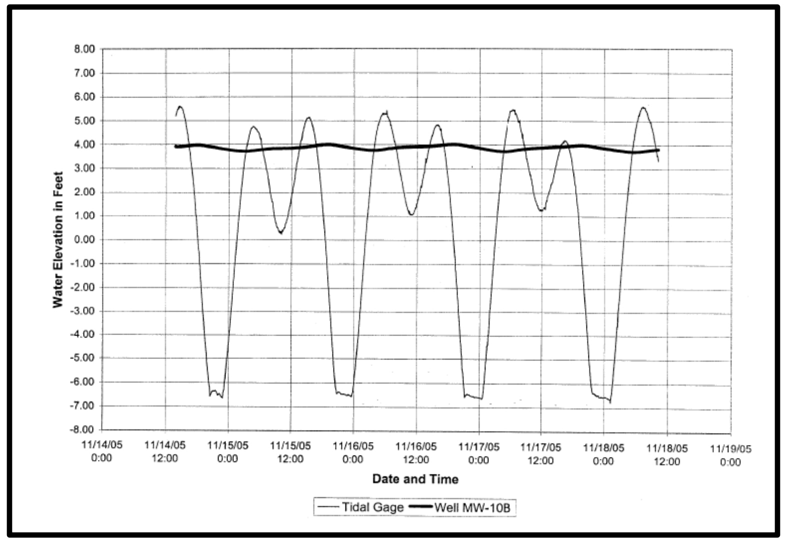
Figure 4
Tidal Study Graphs – Northern Portion

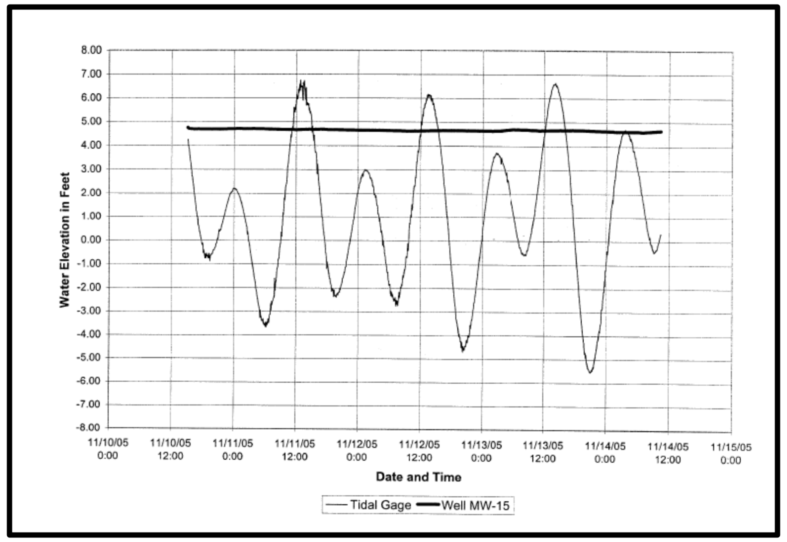


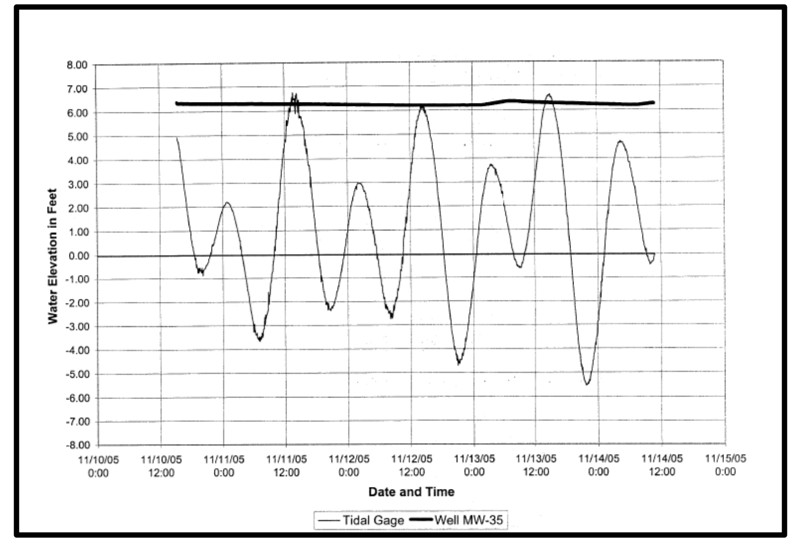


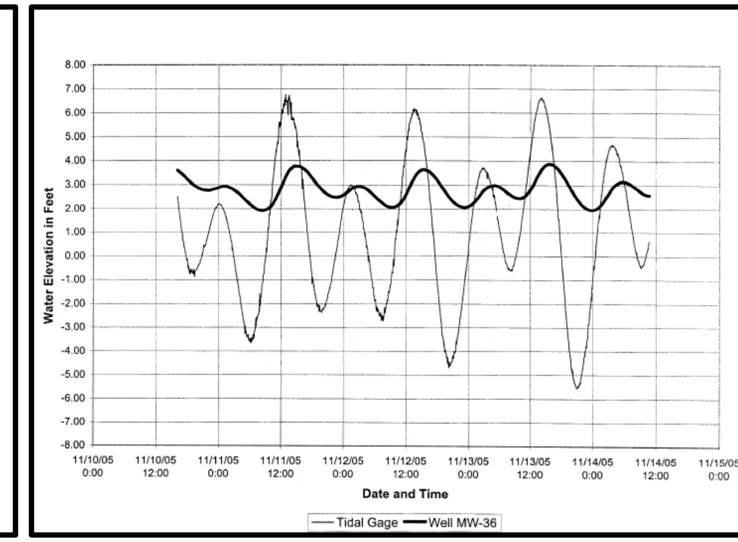


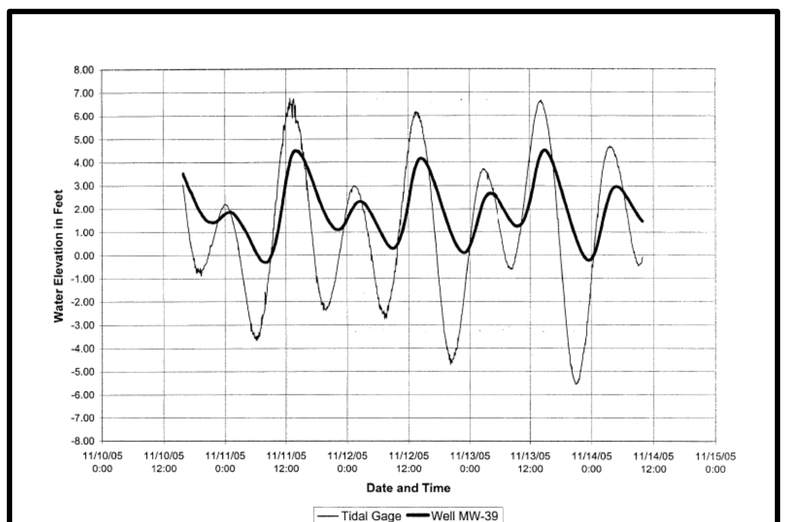


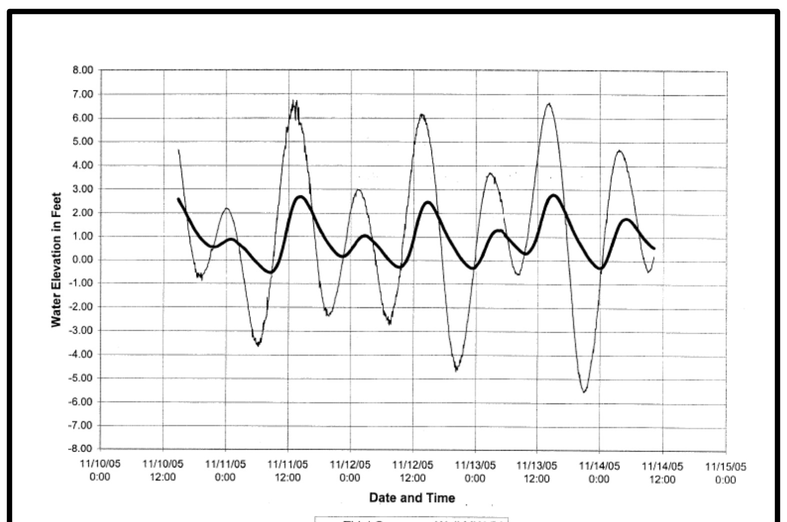






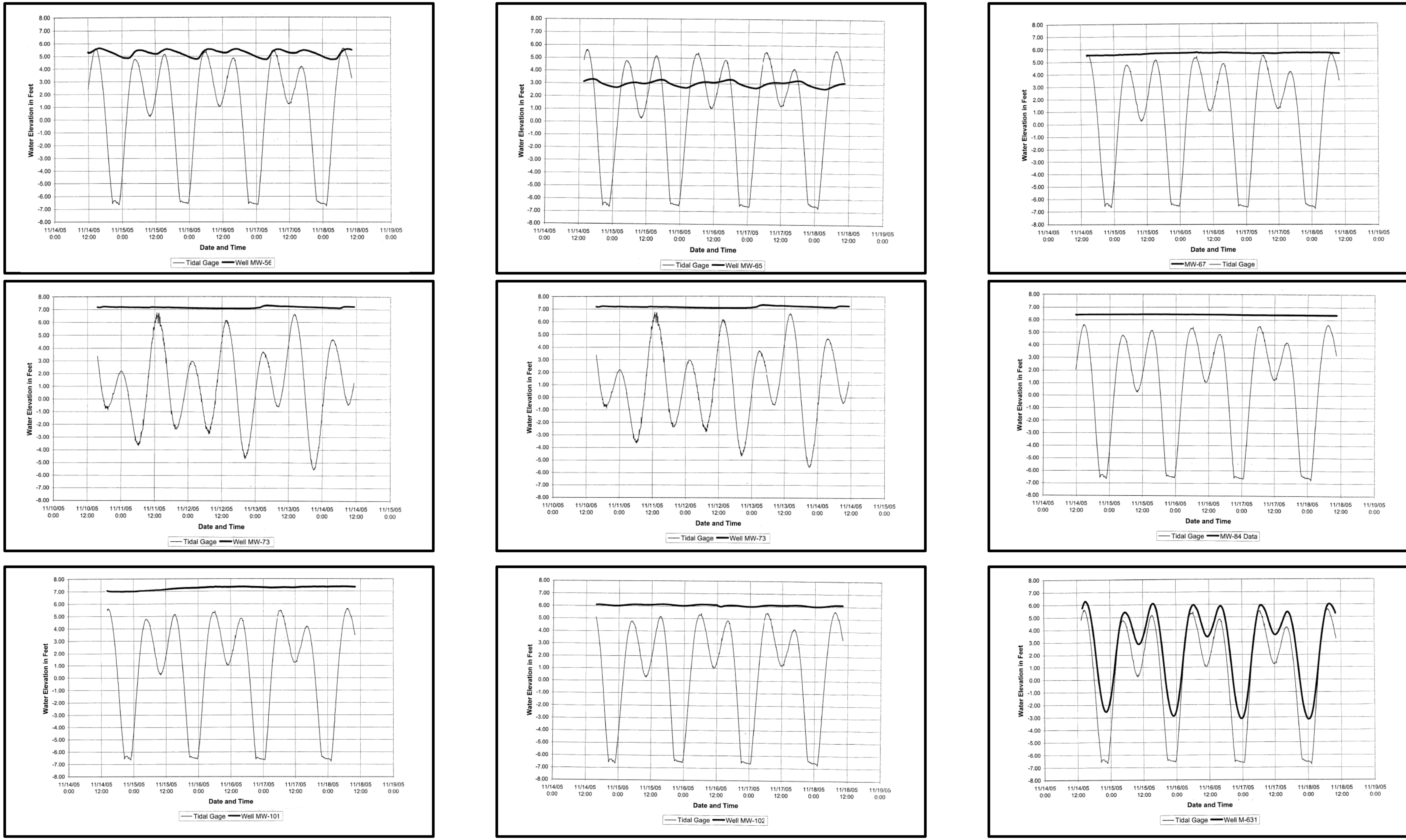






Tidal Graphs – 2005 Groundwater Investigations (2006)

Peter LeDoux
MESSAGe Capstone Project - 2015
Figure 5
Tidal Study Graphs – Central Portion



Tidal Graphs – 2005 Groundwater Investigations (2006)

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Figure 6
Tidal Study Graphs – Southern Portion

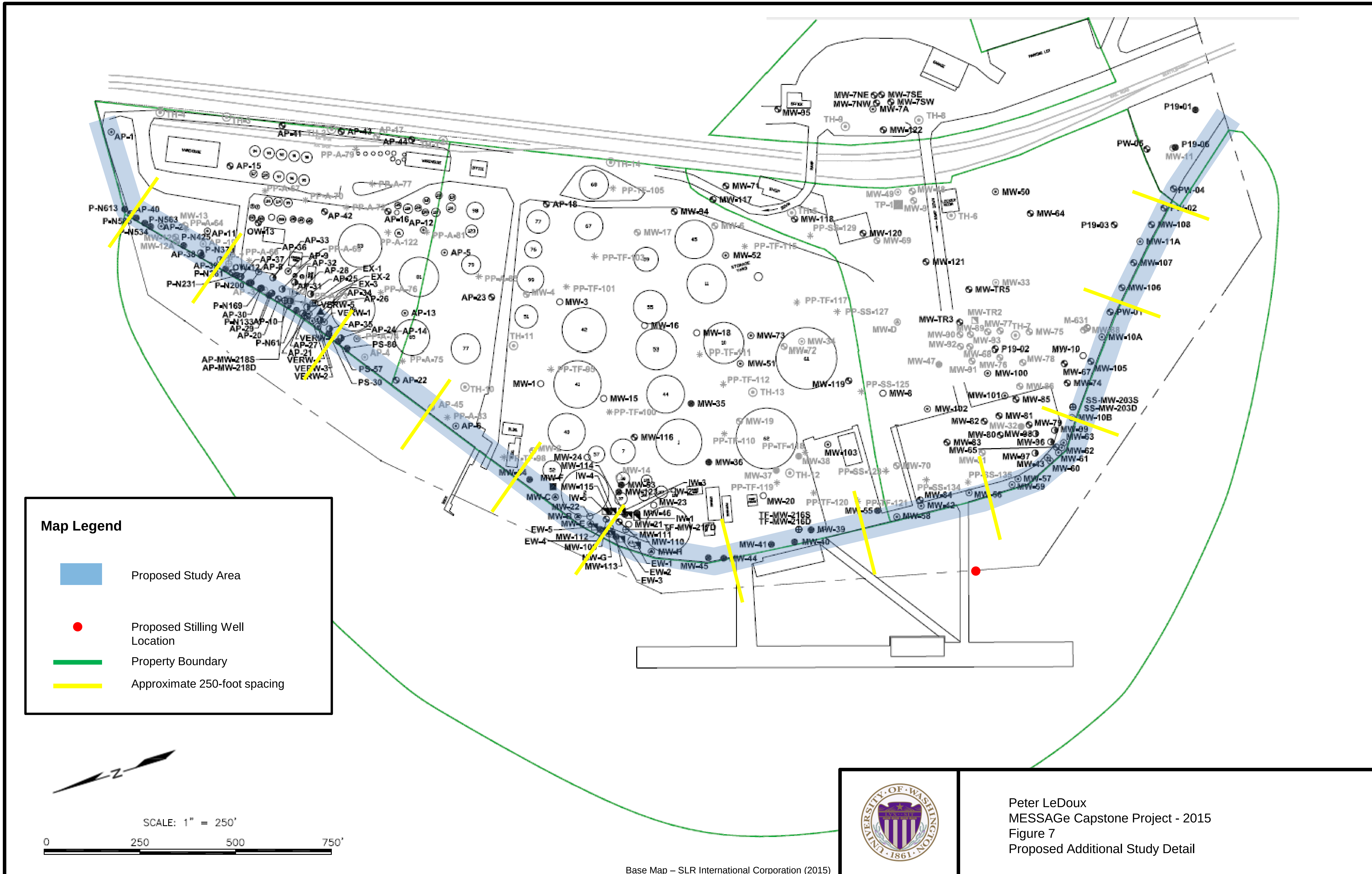
Map Legend
Proposed Study Area
Proposed Stilling Well Location
Property Boundary
Approximate 250-foot spacing
N
SCALE: 1" = 250'
0
250
500
750'
Base Map – SLR International Corporation (2015)
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Figure 7
Proposed Additional Study Detail

TABLES

CAPSTONE PROJECT

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MESSAGe Technical Report Number: 023

Table 1
Previous Tidal Study Detail
University of Washington
MESSAGe Capstone Project

Area	Well Designation	Mean Water Elevation NAVD88 (Feet)	Tidal Efficiency (%)	Tidal Lag (Minutes)	Transmissivity (ft^2/day)[1]
South	M-631	2.79	0.7	26	5,349
	MW-8	5.93	0.02	-	-
	MW-10B	3.88	0.02	-	-
	MW-56	5.25	0.06	-	-
	MW-65	3.00	0.05	-	-
	MW-67	5.68	0.02	-	-
	MW-83	3.16	0	-	-
	MW-84	6.13	0.002	-	-
	MW-101	7.28	0.03	-	-
	MW-102	6.08	0.01	-	-
	Stilling Well	0.69	NA	NA	NA
Central	MW-1	2.53	0.03	-	-
	MW-3	7.26	0.04	-	-
	MW-13	-	-	-	-
	MW-14	2.16	0.05	-	-
	MW-15	4.65	0.01	-	-
	MW-35	6.25	0.01	-	-
	MW-36	2.77	0.17	-	-
	MW-39	1.94	0.42	125	231
	MW-54	0.82	0.28	93	418
	MW-73	7.12	0.02	114	101
	Stilling Well	0.99	NA	NA	NA
North	AP-8	3.36	0.09	98	377
	AP-9	3.52	0.07	-	-
	AP-10	2.07	0.42	102	378
	AP-11	3.58	0.07	-	-
	AP-13	3.26	0.06	-	-
	AP-14	2.92	0.14	100	362
	AP-16	5.30	0.02	-	-
	AP-21	3.32	0.07	-	-
	AP-26	-	-	-	-
	AP-38	3.05	0.14	60	1,005
	Stilling Well	0.80	NA	NA	NA

Notes:

- = Not Available or Not Calculated

[1]Transmissivity was calculated using the tidal lag equation (Fetter pg. 338) by solving for T, and using the calculated storativity from AP-10 of 0.053.

This data retrieved from report reference - 2005 Previous Tidal Study (GI 2006)

(grey shading) = Well located proximate to seawall

Table 2
Previous Hydraulic Conductivity Detail
University of Washington
MESSAGe Capstone Project

Area	Well Designation	Screen Location (Feet BGS)	Average Hydraulic Conductivity (cm/sec)	Average Hydraulic Conductivity (ft/day)	Transmissivity (ft^2/day)[1]
North	AP-9	5-15	2.60E-02	72	1,440
	AP-10	5-15	6.60E-03	19	380
	AP-11	4-14	1.70E-02	49	980
	AP-13	3.5-13.5	1.70E-02	48	960
	AP-15	2.5-15	1.60E-02	44	880
	AP-16	2.5-15	1.80E-02	50	1,000
Central	MW-3	1-9	2.60E-03	7	140
	MW-15	NR	2.50E-03	7	140
	MW-20	NR	1.40E-02	39	780
	MW-73	NR	1.70E-03	5	100
	MW-94	2.5-15	7.70E-03	22	440
South	MW-8	1-9	1.90E-03	5	50
	MW-10B	2-12	1.90E-03	5	50
	MW-65	2-12	3.70E-03	11	110
	MW-83	2-12	4.50E-03	13	130
	MW-84	2.5-12.5	8.30E-03	23	230
	M-631[2]	NR	1.90E-01	524	5,240

Notes:

[1] Values were calculated for the purposes of this project and assume a saturated aquifer thickness of 10 feet for the south data and 20 feet for the north and central data.

[2]Well reportedly screened within deeper aquifer.

This data retrieved from report reference - 2005 Previous Tidal Study (GI 2006)

NR = Not Recorded

(grey shading) = Well located proximate to seawall

Table 3
Hydraulic Balance
University of Washington
MESSAGe Capstone Project

Hydraulic Budget Parameters

Hydraulic Inputs			Unit	**Hydraulic Outputs**			Unit
Site Rainfall	=	1,234,200	ga/in	Site Permeability[1]	=	50%	percent
Up-gradient sources	=	N/A	N/A	Transpiration[2]	=	N/A	N/A
				Evaporation[3]	=	71%	percent
				Site Treatment Operations	=	7,200	ga/day
Site Characteristics			Unit				
Site Area (Within Seawall)	=	45	ac				
Site Rainfall	=	48.5	in/yr				

Hydraulic Budget Calculations

Final Input Calculations			Unit			Unit
Site Area	=	45	ac	x	45,360	ft^2/ac
	=	2,041,200	ft^2			
Gallons Per Inch of Rainfall	=	2,041,200	ft^2	x	1/12	in/ft
	=	170,100	ft^3	x	7.48	ga/ft^3
	=	1,272,348	ga/in			
Total Water Input	=	1,272,348	ga/in	x	48.5	in/yr
	=	61,708,878	ga/yr			

Final Output Calculations			Unit			Unit
Permeability Loss	=	61,708,878	ga/yr	x	50%	percent
	=	30,854,439	ga/yr			
Evaporation Loss	=	30,854,439	ga/yr	x	71%	percent
	=	21,906,652	ga/yr			
Pumping Operations	=	7,200	ga/day	x	365	days
	=	2,628,000	ga/yr			

Water Balance			Unit
Total Input	=	61,708,878	ga/yr
Total Output	=	55,389,091	ga/yr

Total Balance			Unit			Unit
Hydrologic Balance	=	61,708,878	ga/yr	-	55,389,091	ga/yr
	=	6,319,787	ga/yr	/	525,600	mins/yr
Excess Input	=	**12.02**	ga/min			

Notes:
[1]Property permeability estimated upon visual appearance and stormwater convayance.
[2]Property transpiration estimated by lack of vegitation throughout the property.
[3]Property evaporation based upon evaporation potential (pan data/precipitation = 71%).
N/A = Not applicable
ga = Gallons
yr = year
min = minute
mos = months
ac = acre
in = inch
ft = feet (square, cubic, etc…)