Retention/Irrigation Systems:
Performance Assessment and Recommendations for Improvement

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Abstract

In accordance with the 1992 Save Our Springs (SOS) ordinance, the City of Austin requires water quality stormwater control measures (SCMs) to meet stringent pollutant load reduction standards within the Contributing and Recharge Zones of the Barton Springs Segment of the Edwards Aquifer. The most common SCM implemented to comply with this ordinance is the retention/irrigation system, which captures and holds a regulated volume of stormwater runoff before irrigating it to an area of land. A fundamental design assumption of this system is the complete infiltration of the captured volume into the soil, preventing any surface discharge to receiving waters. Driven by inspector feedback describing chronic performance deficiencies with retention/irrigation systems, Austin Watershed Protection conducted a review of inspection data, maintenance records, and recurring notices of violations. The performance of retention/irrigation systems was modeled using long-term continuous simulation methods to assess volume reduction and pollutant removal efficiency. Analysis of the model results, review of inspection data, and discussion of maintenance observations revealed critical problems resulting primarily from 1) failure of the mechanical and electrical system components intrinsic to high-pressure spray irrigation, and 2) inadequate infiltration capacity of irrigation field soils. Irrigation system components including pumps, controls panels, distribution lines, and spray heads were found to be particularly vulnerable to failure. The problem of infiltration capacity was found to be a result of overestimated design infiltration rates, irrigation on slopes, and/or insufficient application area. Recommendations to address these issues include substantial revisions to the applicable sections of the Environmental Criteria Manual. Notable recommendations include replacing spray irrigation with an alternative method of applying captured stormwater to infiltration fields, as well as improvements to the protocol for estimating soil infiltration rate.

Keywords: Stormwater Control Measure, Retention/irrigation, Water Quality Control

Introduction

History of Retention/Irrigation and Operating Permits

In 1992, the Save Our Springs (SOS) Ordinance was enacted to mandate non-degradation water quality controls within the Barton Springs Zone and its contributing zone, specifically in areas under the City of Austin's planning jurisdiction. The SOS initiative is codified in Article 13 of the Land Development Code (LDC), §§25-8-511 through 25-8-522. Among its requirements, the ordinance mandates enhanced water quality controls designed to ensure that:

> "... no increases occur in the respective average annual loadings of total suspended solids, total phosphorus, total nitrogen, chemical oxygen demand, total lead, cadmium, *E. coli*, volatile organic compounds, pesticides, and herbicides from the site." (§25-8-514)

The above-referenced code language is known as the "non-degradation requirement". To comply with this stringent directive, new water quality treatment techniques had to be developed and implemented. The first SOS water quality system was constructed at the ACC Pinnacle site in 1993. This system is a retention infiltration design, which incorporates a gravity flow system (i.e., no pumps) rather than a retention/irrigation system, however the requirements are essentially the same: capture the regulated water quality volume in the basin and apply this volume to a designated area for infiltration into the subsurface. This also was the first site to be issued an Operating Permit in the Barton Springs Zone. Pursuant to LDC §25-8-233(A) "in the Barton Springs Zone, the owner or operator of a commercial or multifamily development is required to obtain an annual Operating Permit for the required water quality controls."

In 1994 the first retention/irrigation system was issued an Operating Permit: the Overlook, part of the Gaines Ranch development. However, only 12 additional sites were issued Operating Permits though the rest of the 1990's. This low rate of issuance of Operating Permits was likely due to active litigation involving the SOS Ordinance. At the time of these early developments, there were no criteria in the Environmental Criteria Manual (ECM) to guide the design of retention/irrigation systems.

By 2000 more than 20 sites were issued Operating Permits. Just four years later there were over 100, however roughly half of these Operating Permits were for sites subject to the SOS rules at this time, as grandfathered sites still required Operating Permits while being exempt from compliance with the non-degradation standard. In 2004 new criteria for retention/irrigation stormwater controls were added to the ECM including improvements in the system design such as the addition of backup pumps and improved criteria for control equipment. Subsequent criteria amendments have continued to correct design problems that addressed frequent failures. In 2014 the stormwater load analysis tool (SLAT) was created by City of Austin subject matter experts to provide a standardized spreadsheet tool to aid design engineers in sizing compliant water quality ponds and infiltration areas. SLAT implements the equations, calculation steps, and pollutant concentrations which are described in ECM 1.6.9. The prevalence of clay liner failures over a twenty-year period prompted a switch to a more reliable barrier such as the geomembrane liner. In March 2021, the ECM was amended (R161-21.03) to prohibit the use of clay liners for water quality controls in the Edwards Aquifer Recharge Zone.

As of 2025, the Operating Permit program (25-8-233) includes approximately 185 mechanically pumped retention/irrigation systems and approximately 18 gravity-flow retention infiltration systems for commercial and multifamily facilities in the Barton Springs Zone. In addition to these permitted systems, there are roughly 40 retention/irrigation systems maintained by the City of Austin which serve residential subdivisions and approximately 74 additional privately maintained retention/irrigation systems scattered throughout Austin. Property owners are responsible for inspecting retention/irrigation systems a minimum of six times per year (ECM 1.6.3.C.5.c). All systems within the Operating Permit Program are required be inspected by City of Austin staff annually pursuant to the Operating Permit requirements. Retention/irrigation systems that do not have an Operating Permit are inspected every three years by City of Austin staff. The 40 systems mentioned above that are maintained by the City of Austin are inspected six times per year either by City staff or by a contractor. Historically, limited staff resources have made the completion of all required inspections, and timely resolution of noncompliance issues a challenge.

In addition to retention/irrigation systems, there are approximately 20 rainwater harvesting systems at commercial or City-maintained facilities which incorporate pumping requirements and infiltration areas that are very similar to retention/irrigation systems (see ECM 1.6.7.D and 1.6.7.A). The current cumulative number of retention/irrigation ponds is approximately 337 (319 pumped and 18 gravity flow). As of 2025, an additional ~20 retention/irrigation systems are anticipated to be built; these either have an approved site plan permit but have not yet initiated construction or have not yet completed the permit review process.

Non-Compliance of Contemporary Systems

Retention/irrigation systems are designed to capture and infiltrate a regulated volume of water to meet the non-degradation standard set by the SOS ordinance. However, is has been observed by inspectors and other City staff that certain aspects of retention/irrigation design criteria make these systems susceptible to failure. While older systems are more vulnerable, even newer ones built under current criteria are not immune to mechanical and design flaws. When mechanical equipment fails or infiltration areas don't perform as expected, the non-degradation standard may not be met.

Under §25-8-233(C), the City can verify a water quality control's operating condition through inspections by authorized Austin Watershed Protection (AWP) pond inspectors. These inspectors evaluate system performance, recommend corrective actions, and document non-compliance as part of the Operating Permit program. A review of inspection records and discussions with senior inspectors reveal the following common problems with retention/irrigation systems:

- Mechanical failure (e.g. faulty control boards, panel components, bulbs, wiring, pumps, irrigation system components)
- Inadequate infiltration (e.g. shallow soil depth, small irrigation area, slopes, low permeability)
- Surface runoff from irrigation areas leaving the site
- Failure of pond liners and leaking of pond basins

The design requirements for retention/irrigation systems have evolved since 1994, leading to variable compliance requirements based on which regulations were in effect when a system was permitted. It would be inappropriate to combine and evaluate all available inspection data because improvements to design criteria over time have resolved many issues. Similarly, it would be inappropriate to review only the most recent inspection data from newer systems because a sufficient period of time would not be available to document problems. The three-year period of 2016-2018 was selected as the period of interest to characterize inspection findings because these systems are old enough to have a robust period of inspections, while being new enough to have designs following contemporary criteria. Since 2016, the design and inspection requirements for new systems have remained relatively stable. The following list is a summary of retention/irrigation system inspections and compliance from the Operating Permit program between 2016 and 2018.

- FY16: 164 retention/irrigation controls inspected.
    - 59% had at least one non-compliant inspection, and
    - 40% remained non-compliant by the end of the fiscal year.
- FY17: 165 retention/irrigation controls inspected.
    - 57% had at least one non-compliant inspection, and
    - 47% remained non-compliant by the end of the fiscal year.
- FY18: 176 retention/irrigation controls inspected.
    - 61% had at least one non-compliant inspection, and
    - 40% remained non-compliant by the end of the fiscal year.

This data is concerning because it indicates that in any given year approximately half of all retention re-irrigation ponds are noncompliant. Even more concerning, over the three-year period from fiscal year 2016 to 2018, less than a fifth (32 controls) of all inspected facilities were consistently compliant, meaning that their inspection reports never included any non-compliance issues.

This data reveals that only about 20% of the controls are operating correctly on a long-term basis without apparent failures. It may be concluded that the remaining 80% of controls are not consistently operating as designed and therefore are not providing the designed water quality treatment level of service. Failures that result in untreated or incompletely treated stormwater discharging to receiving waters are controls that are not compliant with SOS ordinance. Runoff may occur due to failures in the high-pressure sprinkler systems such as broken sprinkler heads/lines or other imbalanced loading to the irrigation field. Additionally, failures such as blocked heads/lines, clogged pumps, electrical problems in the panel, and/or recycling of water in the system due to lack of presumed infiltration capacity can lead to the retention pond holding water for longer than designed. Retention ponds that do not maintain available volume for incoming storm events are unable to capture and treat the designed water quality volume resulting in untreated water bypassing the system. Systems that are not operating as designed are delivering a substandard level of stormwater treatment within the sensitive Barton Springs Zone. There is a need to change the relevant criteria as the number of systems designed and constructed with current design criteria continues to increase.

In order to further understand the types and frequency of failures that lead to a system being non-compliant in newer systems, and to substantiate that the data from FY16-18 reflects the condition of more recently constructed systems an additional analysis of retention/irrigation systems inspection data from October 1, 2018, and December 31, 2021 was completed. Of the total additional 582 inspections reviewed, only 39% (227 inspections) were fully in compliance, while the remaining 61% (355 inspections) were identified as not compliant for one or more deficiencies. This is generally consistent with the compliance rates from the FY16 to FY18 data.

Of the 355 non-compliant inspections, 274 recorded a single failure type, while 81 recorded multiple simultaneous types of failure. This indicates that most non-compliant inspections (77%) involved a single failure, but a significant portion (23%) featured multiple concurrent issues. Overall, this dataset reflects a high frequency of non-compliance, with a variety of failure types. Due to the complexity of these systems, there are many potential failure points, and the data reflects this. System failure types for non-compliant inspections conducted between 1 October 2018 and 31 December 2021 are summarized in Figure 1.

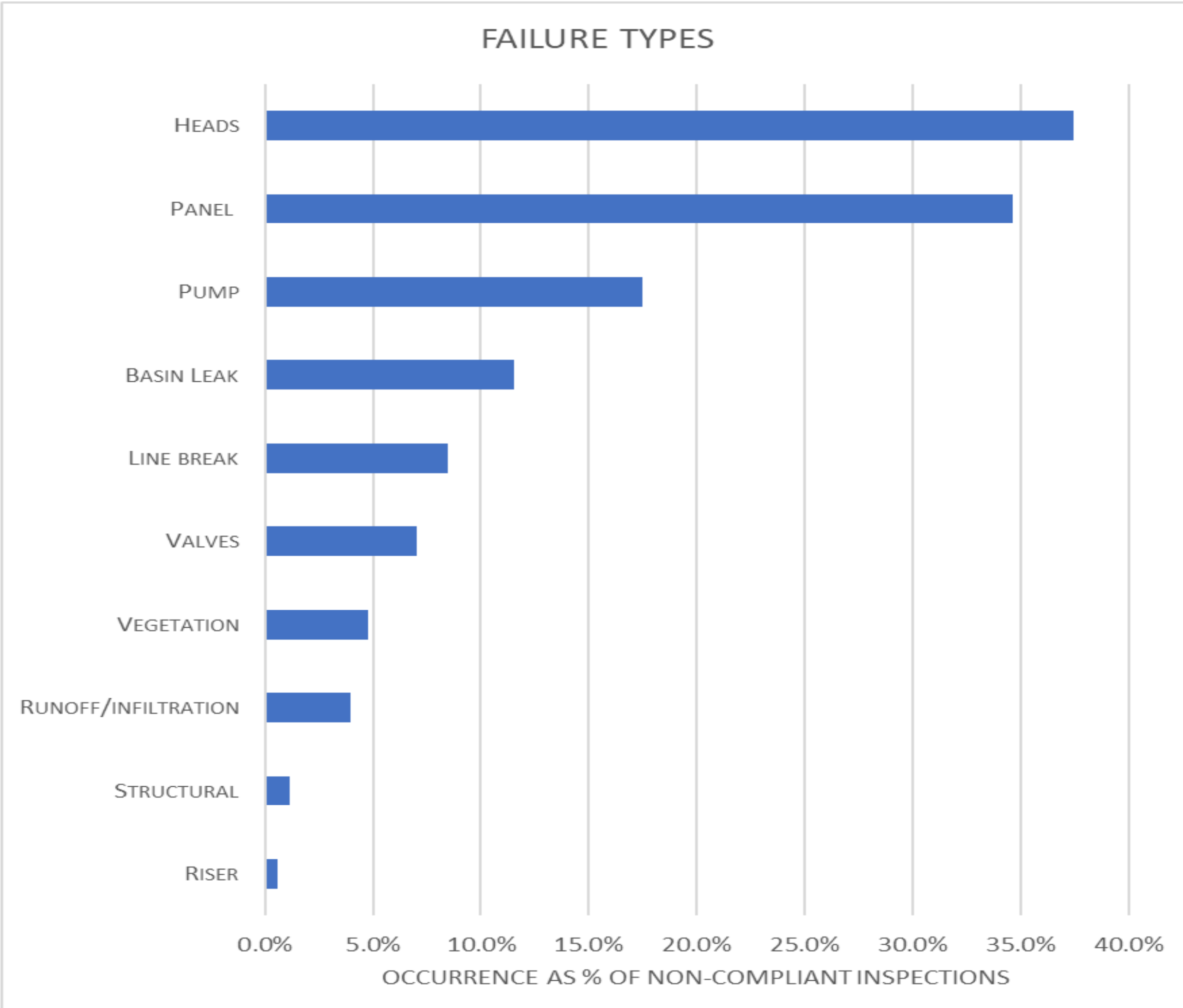

Figure 1. Summary of inspection data October1, 2018 through December 31, 2021. Bars reflect the percentage of time each failure type is non-compliant for the total number of inspections. The total of all bars will not add up to 100% because they are not a percentage of all failures.

Failures of mechanical equipment and irrigation equipment occurred most frequently. Since a single inspection can reveal more than one issue, the percentages shown below represent the frequency of each failure type rather than parts of a whole. The most common failure types were:

- Heads – sprinkler head damage or malfunction (37.5%)
- Panel – related electrical or mechanical problems (34.6%)
- Pump – failure of mechanical/electrical pump components or clogging (17.5%)
- Basin leaks – liner failure or other pathways circumventing the infiltration process (11.5%)
- Line breaks – damage to PVC lines (8.5%)

High pressure irrigation system components were the primary location of system failure. Specifically, broken and clogged sprinkler heads were the most frequent point of failure. Overall, mechanical failures including issues with pumps, panels, and irrigation components were present in almost two-thirds (~64%) of all completed inspections. The following sections provide details on the most common reasons for failure as identified in Figure 1.

Sprinkler Heads

The types of sprinkler heads typically used for retention/irrigation systems are designed to pass relatively clean water, free from most particulate matter. However, stormwater runoff contains a myriad of solids of varying size and texture, including inorganic particulates from soil, sediment, sand, small rocks, and trash, as well as organic particulates from seeds, vegetation, arthropods, and algae. As a result, sprinkler heads which irrigate stormwater tend to clog. The resulting backpressure can cause a range of failures, from heads that blow off completely to cracked heads or heads that stop rotating, any of which could overload a portion of the irrigation area. The failure of a single sprinkler head can lead to a cascade of problems. For example, when a head blows off, high-pressure jets of water may erode the soil, and the increased volume of water can exceed the area's infiltration capacity, causing runoff that bypasses treatment. When one head fails by delivering too much water, the other heads receive less pressure than designed, reducing the system's overall effectiveness by failing to evenly distribute water to other areas of the irrigation field.

Small cracks or malfunctioning heads can cause vegetation to grow faster nearby. Tall vegetation further impedes irrigation and concentrates water around the spray head, causing it to exceed the area's infiltration capacity. As a result, water runs off-site, bypassing treatment. Additionally, the land's variable slope can increase or decrease the hydraulic head in the lines, leading to variable pressure on the heads. This, in turn, alters the amount and range of water being irrigated. Beyond clogging and regular wear, sprinkler heads are also vulnerable to damage from routine mowing. This can occur either from mower blades hitting a head that is stuck in the "up" position or from tires running over them.

In the long run sprinkler systems can impose significant maintenance costs. These costs include not only spot repairs and replacements of malfunctioning components, but also full system replacements due to normal wear and tear on the sprinkler heads. In addition to the costs for heads, the pipes themselves routinely break due to soil movement (shrink/swell particularly with clay soils) and cracking from mowers or UV exposure. Cracked pipes which have allowed the ingress of soil sediments require replacement or cleaning for the affected portions of the system, which sometimes extends to the entire pipe system. Since a standard mowing regime is frequently the cause of sprinkler damage and costly repairs, alternative maintenance methods such as string trimming are often implemented, however these also tend to be more expensive.

Inspectors and owners have worked together to implement various creative and engineered retrofits to try to bring failing systems into compliance by resolving the source of chronic failures. Unfortunately, these attempts either have not been reliable or have created new problems as bad or worse than the original problem. For example, elevating sprinkler heads on riser pipes was attempted to address the common problems of vegetation blocking the spray of sprinkler heads and mowing crews not seeing spray heads. This strategy improved visibility of the heads and reduced obstruction of low vegetation, however it did not resolve the clogging/breaking of heads and resulted in additional problems including increased exposure to UV damage, increased vulnerability from damage by vandalism, and increased incidence of freeze damage to lines and heads in the winter. Another example of a retrofit that was less successful than anticipated is increasing the level of filtration by substituting a sand filtration basin, rather than a retention pond, before stormwater is drawn into the pump. The additional filtration process was successful in removing much of the solids and reducing clogs in the lines and sprinkler heads. Prolonged inundation in the pond encourages the growth of algae, which in turn exacerbates the clogging of the sand bed. Eventually, continued or frequent restriction of flow through the filter can put a severe strain on the pump, potentially causing the motor to burn out.

Electrical Panels

Although contemporary electrical panels have significantly improved since retention/irrigation systems were first implemented, even modern panels are highly stressed by intense summer heat. High temperatures can cause electrical and mechanical stress, leading to relays failing, wires burning out, and contacts going bad. Increased or variable loads from malfunctioning downstream components, such as pumps, heads, or lines, can shorten the life of panel components. Voltage surges also contribute to this degradation. In addition, small animals and insects like mice, wasps, and ants can cause problems within and around the panel. While inspection data lacks the detail to quantify the contribution of each of these issues, senior inspectors anecdotally report that most problems within panels originate from the high-pressure pump and spray head system. Malfunctions in these systems cause the pumps to run with variable loads through the panel, which generates additional heat and stress on the electrical components.

Pumps

The typical style of pump used in high-pressure spray systems is a submersible well pump. These high-pressure pumps are problematic for stormwater irrigation because they are designed for clean/potable water. Stormwater contains small solid particulates such as bits of trash, plant detritus, algae, invertebrates, soil, and a myriad of other organic and inorganic debris. This debris can stress the interior components of submersible well pumps, as can frequent pump cycling that may result from blockages in the irrigation system and/or filtration bed. In contrast, low pressure pumps called trash pumps, grinder pumps, or effluent pumps are designed to effectively pass water containing solid particles. Wastewater lift stations routinely utilize these types of pumps to move sewage effluent containing a significant fraction of particulates with frequent starts and stops.

Basin Leaks

Impermeable basin liners are required for all water quality ponds Edwards Aquifer Recharge Zone, which includes portions of the Barton Springs Zone. This requirement is in place to prevent the conveyance of untreated stormwater runoff into the Edwards Aquifer via subsurface faults, voids, and other relatively direct pathways. Clay liners were previously the standard practice but have been prohibited in the Barton Springs Zone since 2021 when criteria were updated to require more reliable geomembrane liners. Additional recent updates to the Environmental Criteria Manual extended the prohibition of clay liners to all City ponds due to their vulnerability to failure under drought conditions. Although these criteria revisions have improved the reliability of contemporary pond liners, legacy issues persist in ponds with clay liners that were built prior to this prohibition. A pond with a failed liner cannot hold the water quality volume for irrigation purposes without losing a substantial volume to the subsurface. Failure is not uncommon, and repair expenses are substantial (typically $100,000 to $1,000,000 or more). Under current staffing levels, City personnel struggle to keep up with the numerous annual inspections and re-inspections required to ensure compliance where clay liners are installed. In addition, at the time of publication of this report, Austin Watershed Protection inspectors have identified fewer than five experienced contractors with expertise in repairing these complex systems, limiting the rate at which problematic ponds with failed liners can be repaired or retrofitted.

Runoff/infiltration

The generation and discharge of runoff from the infiltration field is a type of problem which according to inspection data occurs only a minor percentage of the time. However, for reasons discussed below, this problem is likely underrepresented in the database. Technically, any amount of runoff from an irrigation field represents a problem since these systems are intended to infiltrate 100% of the captured water quality volume. Runoff problems can have a variety of causes including panel, pump, pipe, or sprinkler system malfunctions as described above in addition to inadequate soil infiltration capacity or steep slopes. Over the last several years, numerous runoff-related complaints have been reported by citizens. According to senior inspectors, these issues are often missed during inspections or attributed to other causes. After a rain event, inspectors are required to visit multiple sites in a single day. Inspections are conducted within a limited timeframe, usually prioritizing the verification of equipment functionality rather than monitoring the entire drawdown period during which fields may become saturated and generate runoff. In some cases, irrigation areas span several acres, making it impractical to inspect the entire boundary for offsite runoff. Furthermore, if multiple component failures or chronic issues exist at a site preventing stormwater application as designed, it may be difficult to discern whether the soil infiltration capacity is adequate to handle the regulated water quality volume.

The soil infiltration rate is a critical factor in the design of a retention/irrigation system because it directly influences the required size of the irrigation field. A higher infiltration rate allows for a smaller irrigation area, while a lower rate necessitates a larger one to effectively dispose of the regulated water quality volume via infiltration. This relationship is crucial for the overall efficacy of the system, ensuring that the volume of water can be absorbed into the soil without causing runoff or flooding. However, the estimation of an accurate soil infiltration rate is achieved inconsistently.

ECM 1.6.7.4 provides guidance on conducting infiltration rate evaluations for the design of retention/irrigation systems, outlining a multi-tiered process that includes both a desktop study and a field study. This assessment is crucial because soil infiltration rates vary significantly based on soil depth, type, and moisture content. A key issue is that the standard ASTM field tests were originally created for the agricultural industry, not for stormwater controls or infiltration-based systems. This raises questions about their suitability for irrigation field design.

A typical retention/irrigation system is designed with a rain sensor that activates after rain events following a short drying window, which may take several hours. After the sensor is dry there is a 12-hour delay prior to irrigation of the field with captured stormwater. Therefore, irrigation typically occurs less than 24 hours after a rain event, when soils may still be saturated from prior direct rainfall and have not recovered their full infiltration capacity. When this happens, site runoff may occur leading to the discharge of un- or under-treated stormwater from the site. The typical design using SLAT does not account for the reduced infiltration capacity of soils as a result of direct rainfall. Models which do account for the effect of soil saturation on infiltration rate are available but are not required by current criteria and do require more time and expertise to implement.

Current criteria allow infiltration rates to be derived from field tests rather than the rate indicated on the available National Resource Conservation Service (NRCS) soil maps when the indicated rate is very low (e.g. 0.00 – 0.02). Site-specific testing and verification is generally preferable to reliance on maps which may be inaccurate. However, field testing may lead to an unrealistically high infiltration rate if the methodology is not rigorously executed or the personnel conducting the testing are not skilled or experienced. Unfortunately, there is no clear standard for performing tests to account for varying conditions of antecedent soil moisture. Soil that is dry infiltrates water at a slower rate than soil that is moist, but not saturated. Soil that is saturated may not infiltrate water at all if there is a confining layer beneath it such as rock or clay. Variability in soil moisture is somewhat accounted for by protocols which require pre-wetting of soils prior to infiltration testing, but the implementation can vary greatly in the field. Furthermore, because soil infiltration rate is highly spatially heterogenous, the number of tests required to adequately characterize the variability in infiltration rate with a given area is high, likely much higher than the number of tests required by current criteria.

Objective

The purpose of this investigation was to identify performance and design deficiencies in retention-irrigation stormwater control systems. A review of inspection report data and senior inspector evaluations helped frame the problem and provided empirical context. A modeling analysis was applied to an existing City-maintained retention/irrigation system that, despite following typical design standards and complying with all modern criteria, has experienced chronic operational challenges and failures. The results of this investigation may:

- Identify the core issues that lead to repeated failures in these systems
- Provide insights to improve design guidance in the Environmental Criteria Manual
- Reduce the frequency and extent of maintenance necessary to keep systems functional and compliant with regulations

Methods

The methods in this investigation include two modeling frameworks: the Stormwater Load Analysis Tool (SLAT) and the EPA's Stormwater Management Model (SWMM). SLAT is a spreadsheet tool developed by Austin Watershed Protection (AWP) staff to aid development applicants and designers. The tool implements current criteria and incorporates:

- Adams & Papa analytical probabilistic methodology with local long-term rainfall monitoring data (Adams and Papa, 2000), and
- AWP-approved pollutant concentrations

The AWP-approved pollutant concentrations are provided in the Environmental Criteria Manual to assist designers and permit applicants in complying with the non-degradation requirement. The development of these pollutant concentrations is documented in City of Austin report CM-09-03 (Glick et.al, 2009) for influent pollutant concentrations, CM-13-02 (Glick et.al, 2013) for SCM effluent pollutant concentrations, and SR-14-10 (Richter, 2010) for SCM bypass pollutant concentrations. Users of the SLAT tool enter values corresponding to characteristics of the site proposed for development (i.e. acreage and impervious cover percentages) and stormwater control measure design parameters. The tool implements closed-form equations from Adams & Papa (2000) for average hydrologic performance and pollutant removal to estimate the average annual pollutant loads discharged from a proposed development and compares the pollutant loading to estimated pre-development conditions.

SWMM is a free and popular open-source model produced by the United States EPA. SWMM uses a rainfall period of record as its main input, along with other inputs including defined pollutant concentrations and stormwater system design. SWMM can model hydrologic and pollution removal performance of a stormwater control system and determine the pollutant loads discharged, volumes of runoff captured or bypassed, and total volume infiltrated. In this investigation, results from the SLAT tool, which uses closed-form analytical formulas to determine average annual pollutant loading and volumes, are compared against results from SWMM, which in contrast to SLAT uses continuous time-step simulation of hydrologic and hydraulic processes. These two models were utilized to assess the performance of a retention/irrigation system in south Austin.

Modeling Approach Development – Flow Routing

All retention/irrigation (R/I) systems share typical design characteristics and layouts. The area of the proposed site to be developed is designed to drain to a retention (or, less commonly, sedimentation/sand filtration) basin of a size adequate to meet code requirements[1]. The total volume of the retention basin is defined as the water quality volume (WQV). The WQV is isolated from subsequent runoff by a splitter structure. Overflows (i.e. bypass flows) are conveyed offsite via the site outfall. The WQV is retained in the retention basin and then, after a lag period typically of 12 hours, is conveyed to the second treatment facility- an area of land known as the irrigation field. The WQV is usually pumped to spray heads distributed across the irrigation field at an overall rate that is intended to not exceed the saturated hydraulic conductivity of the irrigation field soil. Criteria requires that retention basins shall be emptied 72 hours after the end of a rain event which fills or partially fills the basin. Given the 12-hour lag before pumping, this results in a typical pumped irrigation duration of 60 hours. When considering the irrigation duration together with estimated maximum hydraulic loading rate of the soils, designers can calculate the necessary area of the irrigation field. It is the design intent that all water applied via irrigation completely infiltrates or evapotranspirates, with no runoff leaving this part of the site. The only runoff assumed to leave the overall site is the flow which is designed to bypass the retention pond after the water quality volume has entered the system. This condition of 'no site runoff from the irrigation field' is built-in to the SLAT tool when evaluating whether the non-degradation requirement is met. Therefore, in the SLAT tool, it is the total pollutant load of the bypass effluent that must not exceed the pre-development load.

An R/I system can be modeled in SWMM using the discrete hydrologic and hydraulic elements available in the software. Assuming a pumped system, the necessary SWMM elements would include: 1) hydrologic input (rainfall hydrograph representing a locally-valid period of record or design storm), 2) subcatchment (site drainage area to the retention pond), 3) hydraulic splitter structure (node/storage unit) connecting to an outfall for overflows, 4) retention pond (storage node), 5) nodes or outfalls where pollutant concentrations for either bypass or retention pond outflows are imposed, 6) a pump programmed to run on a timer in compliance with criteria, and 7) the irrigation field. Elements 1-6 are straightforward and readily implemented in SWMM. However, there is no tailor-made SWMM element to model the distribution of the WQV over the irrigation field. Three options for modeling irrigation fields in SWMM were initially evaluated. Each modeling option is described below along with benefits and drawbacks:

1. Irrigation Field modeled as a Conduit element, with a user-input transect approximating the cross-section of the irrigation field (Figure 2)
    a. Benefits: Can input slope and roughness to better simulate site characteristics
    b. Drawbacks: Can only model infiltration via a constant rate of seepage loss, so cannot account for infiltration as a function of soil moisture and saturation.
2. Irrigation Field modeled as a Storage Node (Figure 3)
    a. Benefits: Can model infiltration using the Green-Ampt equation, which accounts for soil suction head, saturated hydraulic conductivity, and initial moisture deficit. Can model and track any surface ponding.
    b. Drawbacks: Cannot model conveyance internal to the storage node in order to simulate overland runoff on a sloping site.
3. Irrigation Field modeled as a Subcatchment (Figure 4)
    a. Benefits: Offers the most robust options for modeling infiltration, with a choice of several methodologies (i.e. Green-Ampt, Horton, or Curve Number). Can simulate a sloped site. Accounts for direct rainfall.
    b. Drawbacks: Cannot precisely model or track the extent of any surface ponding or conveyance over a sloping irrigation field.

[1] That the non-degradation requirement is met must be proved with engineering calculations, modeling, or most typically by using the SLAT tool. Outside of the BSZ, the water quality volume is simply defined as a function of the drainage area imperviousness, i.e. the "half-inch-plus" rule, see ECM 1.6.2.A.

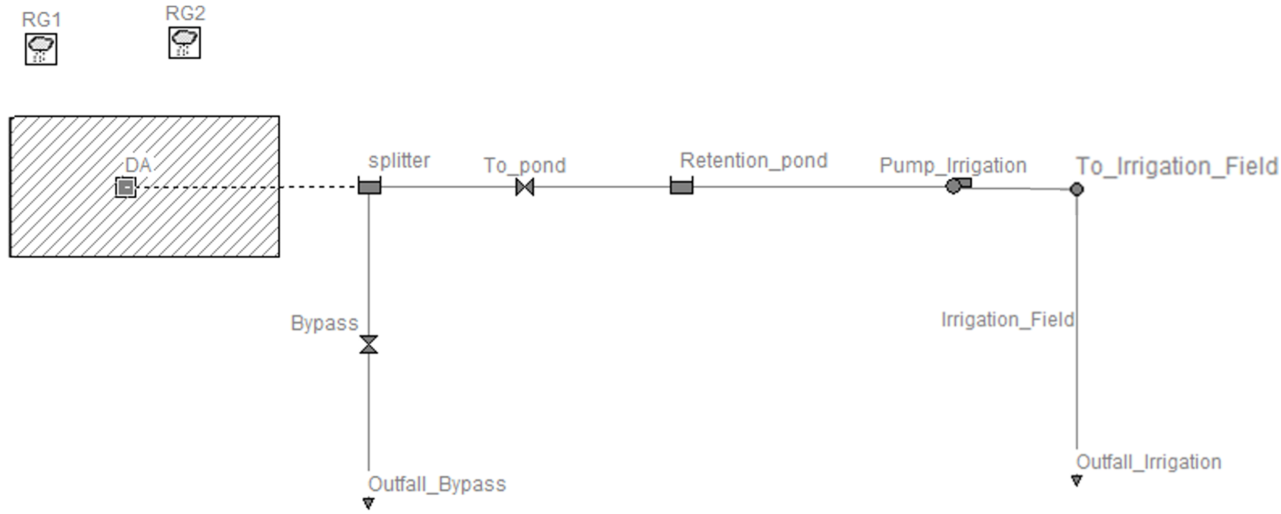

Figure 2- SWMM Model Schematic for Conduit Approach

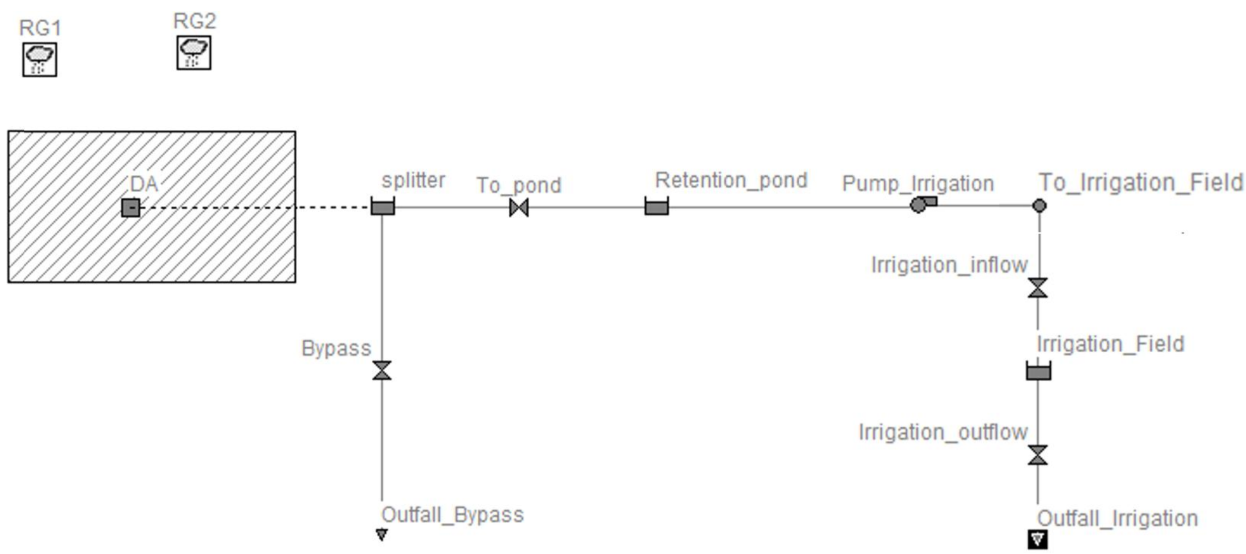

Figure 3 – SWMM Model Schematic for Storage Node Approach

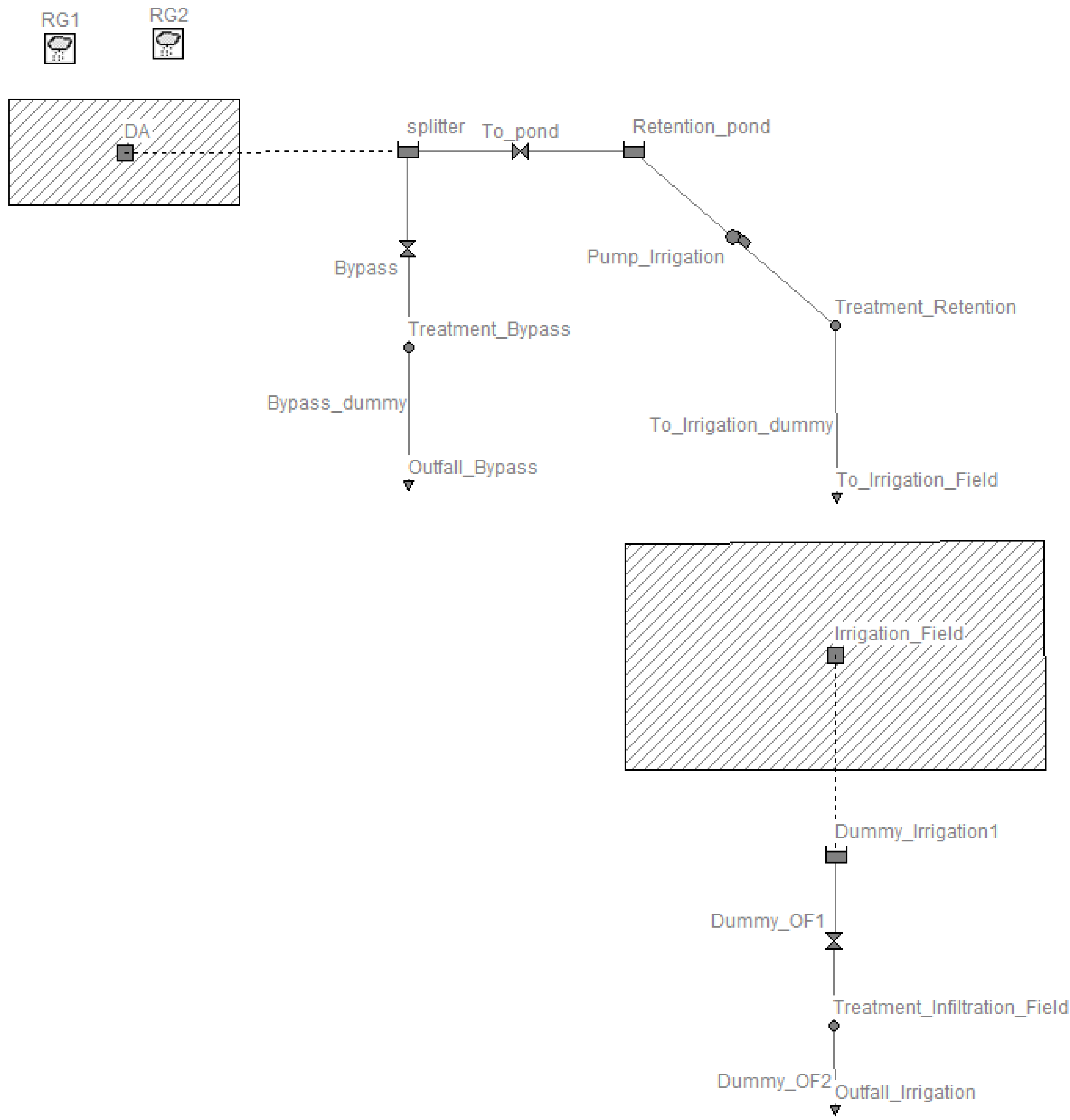

Figure 4 – SWMM Model Schematic for Subcatchment Approach

In practice, the drawbacks of the first two approaches outweigh their benefits. The conduit approach does a poor job of simulating the infiltration in the irrigation field, which is the primary treatment process and so requires accurate representation. Even with a conduit transect derived from site topography and realistic Manning's roughness parameters, pumped irrigation flows are conveyed too efficiently through the conduit transect, resulting in unrealistically low infiltration volumes and unrealistically large site runoff volumes. Similarly, the storage node approach leads to inaccuracies because the model assumes the storage node fills uniformly from the bottom upwards, whereas in reality the irrigation heads distribute flows across the irrigation field which then subsequently infiltrate or runoff and flow to an outlet point. As a result, irrigation flows from the storage node are also conveyed too efficiently to the outlet, resulting in unrealistically low infiltration volumes and unrealistically large site runoff volumes.

Of the three approaches described, the subcatchment approach appears to most accurately simulate the process of uniform spray irrigation over the field and subsequent infiltration or runoff to an outlet point. Although surface ponding cannot be evaluated within a subcatchment, this is not a major requirement since ponding is not an intended performance characteristic of R/I systems. Therefore, the subcatchment method is used to simulate the baseline R/I system in this study.

Modeling Approach Development – Pollutants and Treatment Trains

In this investigation, we follow COA regulatory guidance concerning stormwater pollutant concentrations wherever practical. Pollutant concentrations in stormwater runoff, stormwater control measure (SCM) effluent, and SCM bypass/overflows are defined by ECM Tables 1-10, 1-11, and 1-12, respectively (see Figures 5-7 below). ECM Table 1-10 defines pollutant concentrations in stormwater runoff as a function of drainage area impervious cover. ECM Table 1-11 defines constant pollutant concentrations in SCM effluents which vary depending on the SCM type. ECM Table 1-12 defines bypass flow pollutant concentrations as a function of the SCM water quality volume (WQV), the runoff concentrations specified by ECM Table 1-10, and whether the SCM is first or second in series. In the case of two or more SCMs in a series, the pollutant concentrations are assumed not to increase as they travel through the treatment train. Therefore, for each individual pollutant, the effluent concentration after the final SCM in series is the minimum effluent concentration of any of the SCMs that are in that series (ECM 1.6.9.3.E). In all cases, the following pollutants are defined and regulated by the ECM: chemical oxygen demand (COD), bacteria (E. coli), lead (Pb), total nitrogen (TN), total organic carbon (TOC), total phosphorous (TP), total suspended solids (TSS), and zinc (Zn).

In all SWMM models used in this investigation, pollutants in runoff from the drainage area are represented by assigning direct rainfall with pollutant concentrations according to ECM Table 1-10 (where some concentrations are a function of the impervious coverage of the drainage area, see Figure 5). For simplicity and to remain compliant with current ECM guidelines, wash-off of pollutants from surfaces, pollutant buildup on surfaces, and other spatially- or time-varying processes are not simulated. Flows which are captured in the first SCM in series (e.g., retention basin or sedimentation/filtration) are assigned pollutant concentrations according to ECM Table 1-11 (see Figure 6) before these flows are routed to the irrigation field subcatchment. Flows which may runoff from the irrigation field element are assigned a pollutant concentration, before dilution with rainwater, which is the minimum of ECM Table 1-11, column 1 (for irrigation fields, see Figure 6) and the concentrations associated with prior SCMs in the treatment train. Flows which bypass at the splitter box upstream of the first SCM in series are assigned pollutant concentrations at the outfall according to the SCM 1 Bypass column in ECM Table 1-12, where concentrations are a function of the WQV and influent runoff concentrations (see Figure 7).

The simulation of effluent dilution by rainwater is the one aspect where our modeling approach deviates from the ECM. This deviation is justified given the importance of producing physically accurate results. Usually, SCMs are relatively small compared to their depth so that the effect of direct rainfall onto the SCM is insignificant. However, irrigation fields are so broad and shallow that direct rainfall onto the irrigation field is hydrologically significant compared to the pumped/applied volume[2]. To account for this phenomenon, the volume of direct rainwater falling onto irrigation fields was accounted for but assumed to carry zero pollutant loading. Final effluent concentrations from the irrigation field were determined by calculating a volume-weighted average of the ECM-prescribed effluent concentration diluted by the simulated rainwater volume.

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[2] Over the course of the simulation, the volume of direct rainfall that the irrigation field received was approximately equal to the volume of captured, pumped runoff applied to the field

Pollutant, i		Pollutant Concentration, C_{Ex} or C_D	
		A Site Contains Development (IC ≥ 0%)	B Site Completely Undeveloped (IC = 0%)
COD	mg/L	= 38.9 + 66.6·IC	38.9
E. coli	CFU/100 mL	25000	8370
Pb	mg/L	= 0.00428·exp(2.42·IC)	0.00428
TN	mg/L	2.22	1.19
TOC	mg/L	13.03	13.03
TP	mg/L	0.396	0.124
TSS	mg/L	166	166
Zn	mg/L	= 0.0236·exp(2.18·IC)	0.0236

Figure 5 – ECM 1.6.9.3 Table 1-10 Yearly Runoff as a Function of Impervious Cover

Pollutant	Unit	C_{eff}					
		Infiltration Field	Retention Basin and Rain Gardens without Underdrain	Rainwater Harvesting	Sedimentation/ Filtration	Biofiltration	Approved Alternative SCM
COD	mg/L	38.9	43.79	43.79	22.4	22.4	Applicant Provided
EC	CFU/ 100 mL	8370	11065	11065	4895	4895	Applicant Provided
Pb	mg/L	0.00428	0.00831	0.00831	0.00574	0.00574	Applicant Provided
TN	mg/L	1.19	1.42	1.42	1.07	1.07	Applicant Provided
TOC	mg/L	13.03	11.45	11.45	7.33	7.33	Applicant Provided
TP	mg/L	0.124	0.224	0.224	0.099	0.099	Applicant Provided
TSS	mg/L	166	134	134	20.62	20.62	Applicant Provided
Zn	mg/L	0.0236	0.0453	0.0453	0.023	0.023	Applicant Provided

Figure 6 – ECM 1.6.9.3 Table 1-11 Effluent Concentrations for Approved SCMs

Pollutant	Units	SCM 1 Bypass Concentration, $C_{by,1}$		SCM 2 Bypass Concentration, $C_{by,2}$
		Off-line	**On-line**	
COD	mg/L	= min{$C_{D,COD}$, exp[4.493-0.510(WQV)]	= min{$C_{D,COD}$, exp[4.916-0.545(WQV)] }	= C_{eff-1} ,Table 1-11
EC	CFU/ 100m	= min{$C_{D,EC}$, exp[10.18-0.465(WQV)]	= min{$C_{D,EC}$, exp[10.79-0.624(WQV)]	= C_{eff-1} ,Table 1-11
Pb	mg/L	= min{$C_{D,Pb}$, 0.001·exp[2.882-0.489(WQV)]	= min{$C_{D,Pb}$, 0.001·exp[3.522-0.529(WQV)]	= C_{eff-1} ,Table 1-11
TN	mg/L	= min{$C_{D,TN}$, exp[0.957-0.267(WQV)]	= min{$C_{D,TN}$, exp[1.322-0.236(WQV)]	= C_{eff-1} ,Table 1-11
TOC	mg/L	= min{$C_{D,TOC}$, exp[2.724-0.189(WQV)]	= min{$C_{D,TOC}$, C by = exp[3.112-0.282(WQV)]	= C_{eff-1} ,Table 1-11
TP	mg/L	= min{$C_{D,TP}$, exp[-0.613-0.469(WQV)]	= min{$C_{D,TP}$, exp[-0.223-0.400(WQV)]	= C_{eff-1} ,Table 1-11
TSS	mg/L	= min{$C_{D,TSS}$, exp[5.290-0.934(WQV)]	= min{$C_{D,TSS}$, exp[5.862-0.765 (WQV)]	= C_{eff-1} ,Table 1-11
Zn	mg/L	= min{$C_{D,Zn}$, 0.001·exp[4.610-0.442(WQV)]	= min{$C_{D,Zn}$, 0.001·exp[5.200-0.531(WQV)]	= C_{eff-1} ,Table 1-11

Figure 7 – ECM 1.6.9.3 Table 1-12 Bypass Concentrations

Example System & Model Calibration

In accordance with the objectives of this investigation, an existing R/I system in Autin, TX was modeled following the subcatchment approach described above. The system is located near West Gate Blvd at Cohoba Drive and will be referred to simply as the West Gate pond system (Figure 8). The Drainage ID of the selected system is 620584 in the City of Austin GIS Pond Database and the Maximo Asset ID is 401318955. The pond was permitted in 2009, is owned, operated, and maintained by the City of Austin, and has a typical design for R/I systems incorporating a sedimentation-only (i.e., retention) basin which is drained by a mechanical pump connected to spray heads in an irrigation field adjacent to the pond. Flows which bypass the retention pond are routed through an adjacent flood detention basin before leaving the site. The construction drawings for the pond were obtained and used to determine input parameters for the SWMM model elements, including: subcatchment characteristics, splitter box geometry, weir sizes and elevations, retention pond stage-storage relationship, irrigation field size, soil infiltration rates, and pump characteristics. Additional information about site soils was obtained from the online NRCS Web Soil Survey (NRCS, 2025). Selected applicable sheets from the construction drawings are provided in Appendix B.

Figure 8 – West Gate R/I pond system typical images selected from the 26 Google Earth aerial photos from 2012-2025. Most (85%) of the available images show the retention basin to be either completely inundated (a, b, e) or partially inundated (c) substantiating the observations of inspection staff that the pump/irrigation system is chronically clogged. Note accumulation of algae in stagnant inundation (a), heterogeneous saturation/standing water around some sprinkler heads (c, e), and organization of surface water that flows to the west (bottom left corner) and has been observed as off-site runoff circumventing treatment (c, d). See Appendix A for a table listing antecedent rainfall and basin status corresponding to available aerial imagery.

Interestingly, the plans seem to suggest that at the time of construction the native soils in the irrigation field did not possess adequate infiltration rates (this is confirmed by NRCS soil data which shows a prevalence of clay soil with low infiltration rates in the area). To compensate for this, it appears that soil was allowed to be imported which had an adequate infiltration rate of 0.14 in/hr and placed over the infiltration field's native soil to a depth of 2 ft (see West Gate plans sheet 134, Appendix B). Anecdotally, this irrigation field has been observed by City inspectors to produce significant site runoff. Separate model runs were performed using parameters for the native soil infiltration rate and the imported soil infiltration rate to compare results to actual observed conditions.

Another interesting aspect of this R/I system is that it appears to be oversized relative to the regulatory requirement. The minimum 'Capture Depth' indicated on the plans (per the old ECM Table 1-12) is 1.86 inches, however based on the retention pond stage-storage table, which matches the grading plan, the actual WQV capture depth is 2.43 inches (30% larger than the regulatory requirement at the time of permitting)[3]. Assuming the pond was constructed in accordance with the plans, the SWMM model represents the pond and irrigation field in their as-built conditions.

To calibrate the model and ensure that the subcatchment produced reasonably accurate runoff volumes, design storm hyetographs representing pre-Atlas 14 rainfall amounts were run through the model and the resulting subcatchment peak flows were compared to the design peak flows. Relatively close approximation to design peak flows were observed for all design storms without requiring significant parameter adjustments (see Table 1).

Table 1- SWMM Peak Flow Calibration for West Gate Pond

Design Storm	Design Flow (from Plans), cfs	SWMM Flow (pre-Atlas 14), cfs	SWMM Error (%)
Q2	10.9	10.61	-2.66%
Q10	19.6	19.72	0.61%
Q25	24.99	24.98	-0.04%
Q100	33	33.72	2.18%

A similar calibration process was completed for the irrigation field to ensure the simulated rainfall-runoff response was reasonable. First, design storm peak runoff rates were estimated for the infiltration field using the Rational Method. The Rational Method "C" values were chosen based on DCM Table 2-3 for "developed, pervious, good condition, flat" surface characteristics. Then, SWMM model parameters for the irrigation field were manually adjusted until the simulated SWMM peak discharges for the 10, 25, and 100-year storms closely matched estimated Rational Method flows (see Table 2). The relative error for the 2-year peak flow was not able to be reduced further without increasing the error for the larger design storms. This was deemed acceptable because the absolute difference was small, only about 0.3 cfs.

Table 2- SWMM Peak Flow Calibration for West Gate Pond- Irrigation Field

Design Storm	Rational Method Flow, cfs	SWMM Flow, cfs	SWMM Error (%)
Q2	1.22	0.9	-26.23%
Q10	2.2	2.14	-2.73%
Q25	3.16	3.18	0.63%
Q100	5.19	5.26	1.35%

[3] Had the current SLAT tool been used for design, the minimum required capture depth would be 1.74 inches

Long-Term Continuous Simulation with SWMM

To evaluate overall system performance for pollutant removal in a way analogous to the SLAT tool, SWMM was used to perform long-term continuous simulation (LTCS) using rainfall data from a designated period of record (POR). If the POR is deemed to be representative of average climatic conditions, then results from the LTCS can be used to compute annual average performance metrics in terms of pollutant removal, load discharge, and runoff capture efficiency (RCE)[4], which are the same metrics the SLAT tool computes using analytical probabilistic equations. The SLAT equations are based on rainfall statistics derived from a particular local POR which has been determined to be representative of current average climactic conditions: hourly rainfall data from the Camp Mabry gage between 2004-2013 (Loucks and Adlong, 2018). In this study, the same POR will be implemented in SWMM to produce results which are as comparable as possible to the SLAT tool. A characterization of the Camp Mabry POR is given below in Table 3.

Table 3: Summary Statistics for the Austin-Camp Mabry Rainfall Period of Record

Statistic	Mabry 2004-2013
Mean rainfall event volume (in.)	0.44
Mean rainfall event duration (hr)	5.66
Mean rainfall event intensity (in/hr)	0.077
Interevent time (hr)	108.5
Minimum Interevent Time (hr)	6
Avg. annual number of rainfall events	76.8
Average Annual total rainfall (in.)	33.4

Even with very similar inputs parameters, however, some differences between the results of SWMM and SLAT should be expected due to significant differences in the calculation methodologies of the two models. The primary difference, stated previously, is in the fundamental approach used to estimate metrics such as pollutant removal, load discharge, and runoff capture efficiency. SLAT *calculates* the metrics using derived, analytical equations which are based on statistical parameters of the chosen POR and assumptions about the probability distribution of the underlying parameter (Adams and Papa, 2000). In contrast, within a user-defined model structure, SWMM *simulates physical processes* including rainfall (timing, intensity and duration), infiltration, evaporation, runoff generation, flow routing & conveyance, and pollutant transport & treatment over user-defined time steps through the length of the POR, and then the desired metrics can be extracted by post-processing the output data.

One specific computational difference between SWMM and SLAT relates to the runoff coefficient (Rv), which is the ratio between rainfall volume and runoff volume. A common parameter in many rainfall-runoff models, it is defined as the fraction of rainfall which becomes converted to runoff and reduces many complex physical processes (rainfall distribution, timing, duration, and intensity, soil moisture, conveyance, infiltration, evaporation, etc.) to a single, empirical value. In SLAT, the Rv parameter is calculated using a linear regression equation which is a function of the impervious cover of the watershed. This equation is based on rainfall and watershed flow monitoring done across the City of Austin over the time period 1981-2009 (Glick et.al. 2009). In SLAT, the Rv parameter is a key input for the equation that computes the average annual runoff volume. This volume in turn is used to compute the average annual

[4] RCE is defined as the overall percentage of runoff which is captured by the facility, rather than bypassed around the facility, calculated on an average annual basis

volume captured in the retention basin, the average annual volume bypassed, and hence the average annual pollutant loads removed by the control or discharged downstream. In contrast, SWMM does not require an Rv as an input. SWMM uses the rainfall POR as the primary input and simulates the runoff response using physics-based equations and user-defined parameters of a subcatchment (subcatchment size, imperviousness, slope, geometry, soil moisture, infiltration, and evaporation). The simulation of infiltration in SWMM considers site-specific parameters which describe the soil characteristics, including the suction head, hydraulic conductivity, and initial moisture deficit, and implements the Green and Ampt method (1911) with modifications for EPA SWMM by Nye et. al. (2015). Simulation of evaporation in SWMM is performed using regional monthly average evaporation rates. Subcatchment depression storage and surface roughness are also considered when generating runoff timing, volumes, and rates. Simulation of all these processes is conducted at each time step in response to rainfall input, and at the end of the simulation the runoff coefficient is computed as an average value from the recorded results. To summarize: in SLAT, the Rv parameter is estimated and affects all subsequent results, whereas in SWMM the Rv can be viewed as a summary output generated at the end of the simulation. Although the parameter is estimated, the Rv value may be viewed as a key SLAT input to which all other SLAT results are very sensitive. Arguably, overdependence on the single parameter estimate of Rv represents a significant vulnerability in the computational methodology upon which the SLAT tool is built.

A third way in which SWMM and SLAT differ is that SLAT assumes that all runoff captured in the retention basin will be fully infiltrated in the irrigation field, and only considers loads discharged via the bypass to determine whether the SCM meets the non-degradation requirement. While the underlying Adams & Papa equations (provided in ECM 1.6.9) do allow for the calculation of an annual overflow volume from the infiltration field if the user-entered water quality volume infiltrated is less than the water quality volume captured by the retention pond, the ability to consider such cases is not implemented in SLAT. Implementation would be difficult because there is no simple equation for calculation or estimation of the water quality volume infiltrated. Therefore, possibly for computational convenience, the typical assumption imposed by SLAT for controls in the Barton Springs Zone is that these WQVs must be equal, i.e. all of the WQV must be infiltrated. Because of this assumption, SLAT forces the size of the infiltration field to be exactly large enough to infiltrate the captured volume over the specified application time period (60 hours), considering the user-input constant infiltration rate of irrigation field soils. In other words, SLAT *prescribes* the required irrigation field size for each site. SLAT does not have the capability to evaluate the effect of soil saturation (from pumped flows and/or direct rainfall) and runoff from the irrigation field on the overall pollutant load equivalency. Inspection reports indicate that runoff from irrigation fields is commonly observed at some sites, and according to current inspection protocol if any runoff is generated from an irrigation field, then the site is considered non-compliant. Practically speaking, this is an oversimplification. An R/I system which is generating runoff from its irrigation field may or may not be in compliance with the non-degradation requirement, depending on the total average annual pollutant loads being discharged from the bypass and the irrigation field combined. SWMM, in contrast to SLAT, has a robust capability to simulate soil saturation, infiltration, and runoff resulting from both the pumped/irrigated volume as well as direct rainfall, and can track pollutant loads discharged from all parts of the site. Therefore, SWMM is able to answer a question which SLAT cannot, which is whether or not the presence of runoff from an irrigation field represents non-compliance with the non-degradation requirement.

To summarize, SWMM significantly differs from SLAT in its fundamental modeling approach (simulation vs calculation), and this difference is most saliently manifested in the ways SWMM handles and reports the runoff coefficient and considers soil infiltration. SWMM is a more complex and arguably a more physically accurate model which was utilized to evaluate R/I system performance, as discussed in the following sections.

Results

Existing Conditions Results for West Gate Pond

SWMM was used to simulate the performance of the West Gate R/I system in response to the Camp Mabry rainfall POR. Results were compared to SLAT outputs for the same site. A separate model run in SWMM was created to represent the pre-development condition (where the drainage area had 0% impervious cover). Model results are divided into two categories: ‘quantity’ results, concerning hydrologic performance in terms of average annual volumes of runoff received, captured, bypassed, infiltrated, and discharged; and ‘quality’ results, concerning pollutant treatment performance in terms of average annual loads received, bypassed, and discharged for each pollutant regulated by the ECM. In addition, results from each modeled scenario are analyzed in three different ways to facilitate, clarify, and extend the comparison with SLAT. These analysis paradigms are referred to as “Simple”, “Water Quality Volume (WQV) Only”, and “Overall (Including Direct Rainfall)”. The “Simple” analysis assesses performance in a way that is analogous to SLAT, in that all of the volume applied to the irrigation field is assumed to fully infiltrate, and only bypass flows are considered for Runoff Capture Efficiency (RCE) and Load Equivalency Factor (LEF)[5] calculations (ignoring any SWMM-simulated runoff from the irrigation field). The “WQV Only” and “Overall” analyses do not apply to SLAT, since they consider the fate of runoff volume and pollutants applied to the irrigation field resulting from simulation of soil saturation, infiltration, and runoff generation. In the “WQV Only” analysis, only the volume captured by the retention pond is applied to the irrigation field- i.e., no direct rainfall is allowed to fall on the field and influence soil moisture, contribute to infiltration, or dilute pollutant loads. The analysis was included to help understand the fate of the pollutants which are intended to be captured and treated by the R/I system (it is important to clarify that the intent of the criteria is not to require capture and treatment of pollutant loads in runoff generated by direct rainfall on the irrigation field). Finally, the “Overall” analysis is the most inclusive and physically accurate in that it considers the volume applied to the irrigation field from spray heads as well as from direct rainfall in the accounting of infiltration, runoff, and pollutant loads. Tables 4 and 5 below present ‘quality’ and ‘quantity’ summary results for existing conditions model results from both SWMM and SLAT.

[5] LEFs are used to help easily understand the loads discharged by the proposed SCM relative to the predevelopment load and are defined for each regulated pollutant as the average annual load discharged by the SCM post-development divided by the average annual pre-development load from the same drainage area. For a development to be compliant with the SOS ordinance non-degradation standard, LEFs for all regulated pollutants must be less than 1.0

Table 4: 'Water Quantity' Results for SWMM and SLAT Models of Existing Conditions

Model/Scenario	Runoff Coefficient (Rv)	Runoff Received (gal/yr)	Runoff Captured in Retention Pond (gal/yr)	Runoff Bypassed (gal/yr)	Volume Infiltrated - from WQV Only (gal/yr)	Volume Infiltrated - including Direct Rainfall (gal/yr)	Site Runoff - from WQV Only (gal/yr)	Site Runoff - including Direct Rainfall (gal/yr)	RCE, simple	RCE, WQV Only	RCE, Overall (incl. Direct Rainfall)
SWMM Austin Camp Mabry hourly 2004-2013	0.710	2,490,000	2,280,000	253,000	1,500,000	2,410,000	389,000	1,320,000	90%	74%	65%
SWMM Austin Camp Mabry hourly 2004-2013 with DA 'Sandy Loam' soil parameters	0.626	2,200,000	2,090,000	155,000	1,400,000	2,320,000	322,000	1,240,000	93%	78%	67%
SWMM Austin Camp Mabry hourly 2004-2013 with DA 'Sand' soil parameters	0.608	2,130,000	2,070,000	111,000	1,400,000	2,310,000	314,000	1,230,000	95%	80%	68%
SWMM Austin Camp Mabry hourly 2004-2013 with Irrigation Field Imported Soil (0.14 in/hr)	0.710	2,490,000	2,280,000	253,000	2,190,000	4,030,000	0.00	170,000	90%	90%	91%
SLAT Outputs with SWMM Rvs	0.710	2,190,000	2,100,000	94,600	2,100,000	n/a	0.00	n/a	96%	n/a	n/a
SLAT Outputs with default parameters	0.566	1,750,000	1,690,000	55,700	1,690,000	n/a	0.00	n/a	97%	n/a	n/a

**All gal/yr values have been rounded to three significant figures*

Table 5: 'Water Quality' Results for SWMM and SLAT Models of Existing Conditions

Model/Scenario	TSS Load Equivalency Factors			Zn Load Equivalency Factors			Pb Load Equivalency Factors			TN Load Equivalency Factors			TP Load Equivalency Factors		
	Simple	WQV Only	Overall	Simple	WQV Only	Overall	Simple	WQV Only	Overall	Simple	WQV Only	Overall	Simple	WQV Only	Overall
SWMM Austin Camp Mabry hourly 2004-2013	0.03	0.37	0.63	0.40	0.81	1.81	0.34	0.76	1.77	0.31	0.73	1.19	0.38	0.80	1.72
SWMM Austin Camp Mabry hourly 2004-2013 with 'Sandy Loam' soil parameters	0.02	0.30	0.56	0.24	0.59	1.52	0.21	0.56	1.50	0.19	0.54	0.98	0.23	0.58	1.43
SWMM Austin Camp Mabry hourly 2004-2013 with 'Sand' soil parameters	0.01	0.29	0.54	0.17	0.51	1.43	0.15	0.49	1.42	0.14	0.47	0.92	0.17	0.50	1.35
SWMM Austin Camp Mabry hourly 2004-2013 with Irrigation Field Imported Soil (0.14 in/hr)	0.03	0.03	0.11	0.40	0.40	0.58	0.34	0.34	0.53	0.31	0.31	0.43	0.38	0.00	0.55
SLAT with SWMM Rvs	0.02	n/a	n/a	0.24	n/a	n/a	0.21	n/a	n/a	0.19	n/a	n/a	0.23	n/a	n/a
SLAT with default parameters	0.05	n/a	n/a	0.59	n/a	n/a	0.51	n/a	n/a	0.46	n/a	n/a	0.57	n/a	n/a

**LEFs for COD, E. coli, and TOC omitted for brevity*

Discussion of Existing Condition Results from SWMM

The model results from SWMM for the West Gate R/I facility show that the system captures about 2.5 million gallons and bypasses about 250,000 gallons of stormwater annually. The results for volume infiltrated and volume discharged from the irrigation field depend greatly on the analysis method, i.e. whether or not direct rainfall and/or soil saturation are accounted for. The volume infiltrated when accounting for direct rainfall to the irrigation field is 65% greater compared to the result when accounting for only the water quality volume (WQV) being applied to the irrigation field. The volume discharged when considering direct rainfall is 285% greater compared to the result when considering only WQV. Consequently, the LEFs accounting for direct rainfall are all higher than the LEFs considering only WQV. For the pollutants analyzed, almost all the LEFs accounting for direct rainfall exceed 1.0, indicating non-compliance with the SOS non-degradation requirement. The 'Simple' analysis method, on the other hand, results in very low LEFs across the board. This stark disagreement among the LEFs for different analysis methods stems from the assumption of the 'Simple' analysis that all captured WQV is completely infiltrated. Clearly, this assumption is overly optimistic for the modeled system at West Gate, as will be discussed in the next section.

Comparison of Results from SWMM vs SLAT

As expected, there were significant differences between the SWMM model results and SLAT results for the West Gate R/I system. The first major difference is that the SWMM-calculated runoff coefficient value is much higher than the SLAT value, resulting in 30% greater runoff and 80% greater bypass volumes, and therefore greater pollutant loads both treated and discharged, in the SWMM results. For reference, the drainage area to the West Gate system is 3.87 acres with 70% impervious cover and an estimated time of concentration of 7.8 minutes (according to construction plans). The SLAT-estimated Rv value is 0.566, whereas the SWMM simulated Rv value is 0.71. When controlling for differences in the runoff coefficient values (i.e., by forcing SLAT to use the same runoff coefficients that the SWMM simulation generated) and depression storage values (using similar values in both SWMM and SLAT), runoff received and runoff captured are much closer between SWMM and SLAT (within about 10%), but SLAT still under-estimates total bypass volume when compared to SWMM by about 60%. The reason for the difference is not apparent. Whatever the reason, the difference appears to be irreducible and inherent to the SLAT methodology.

The SWMM runoff coefficient is sensitive to the infiltration parameters of the subcatchment soil. For example, a soil which has a larger saturated hydraulic conductivity, such as a sandy loam, will result in less rainfall being converted to runoff than a clay soil. An attempt was made to modify the SWMM soil data for the system drainage area to reduce the SWMM runoff coefficient and match the SLAT value. However, even with input soil parameters equivalent to sand, the SWMM Rv (0.608) still exceeded the SLAT value calculated from the linear regression equation (0.566) by about 7%. This comparison suggests that the regression equation used to estimate the runoff coefficient in SLAT may not be applicable City-wide and could be underestimating the true value especially for catchments with high-runoff soils (i.e. clay soils, or hydrologic soil groups C and D). This seems likely in the case of the West Gate R/I system, where the underlying soils contain clay and have relatively low saturated hydraulic conductivity values.

Just as the SWMM runoff coefficient is sensitive to soil parameters, so is the total infiltrated volume. As discussed previously, SLAT assumes 100% of captured runoff is infiltrated, so in SLAT there is no relationship to analyze between infiltrated volume and infiltration rate.[6] In SWMM, the infiltrated volume from the irrigation field is a function of the volume and timing of runoff received and of the soil parameters. The first relationship demonstrated in SWMM is an intuitive one: in general, if more runoff is received, then a greater volume will be infiltrated. Similarly intuitive, the second relationship apparent from the SWMM results is that a soil with a larger value of saturated hydraulic conductivity will be able to infiltrate a greater volume than a soil with a smaller value. Initially, data obtained from the NRCS Web Soil Survey was used to inform the soil parameters in the infiltration field. According to the USGS, the native soils at the West Gate site range from sandy clay loam to clay and have saturated hydraulic conductivity values between 0.06-0.02 in/hr. In model runs utilizing these native soil parameters in the irrigation field, the result was that only 67% of the captured runoff was infiltrated, with the rest being either discharged from the site (15-20%) or lost to evaporation. Runoff capture efficiency ranged from 74-80%, compared to 97% predicted by SLAT, and load equivalency factors for many pollutants exceeded 1.0, which indicates violation of the non-degradation requirement. As mentioned previously, the West Gate design seems to indicate an awareness at the time of construction that the native soils did not possess adequate infiltration rates, and so (according to the plans) soil was allowed to be imported which had an infiltration rate of 0.14 in/hr and placed in a 2 ft thick layer across the irrigation field. When the SWMM model soil data was adjusted to reflect this infiltration rate in the irrigation field, the result was significant. As a result, 100% of captured runoff is infiltrated (actually more than this when accounting for direct rainfall on the irrigation field in addition to retained, irrigated flows). The runoff capture efficiency increased to 90% and load equivalency factors for all pollutants were less than 1.0- i.e., the facility, under this model run, becomes compliant with the non-degradation rule.

While the practice of importing soil with a higher infiltration rate to an irrigation field is currently allowed by the ECM, arguably this practice should be disallowed. It is well understood that overall infiltration rate is controlled by the soil profile with the lowest hydraulic conductivity (Williams et.al, 1998). While the surface layer of imported soil may initially allow for a faster initial rate of 'infiltration', once all the pore spaces available for water storage in this layer are filled[7] then further downward or lateral movement of water will proceed according to the hydraulic conductivity of the underlying soil. If the rate is too low, runoff will be generated at the surface and discharge from the site. Inspectors have observed this behavior at the West Gate site specifically as well as at many other typical sites.
The most important conclusion to be drawn from comparison of SLAT vs SWMM results from the existing West Gate site is that overall R/I system performance greatly depends on an adequate soil infiltration rate of the irrigation field[8]. Therefore, a significant effort should be spent to ensure the accurate assessment of these parameters. More discussion is provided in the Recommendations sections.

Evaluation of Alternative Designs to Treat Runoff in the Barton Springs Zone

SWMM modeling results described above indicate that the existing West Gate R/I pond system is not compliant with the SOS ordinance non-degradation requirement. Given the fact that similar performance issues have been observed by inspectors at other Operating Permit sites, alongside other types of

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[6] However, there is a direct relationship between irrigation field size and soil infiltration rate in SLAT. For example: at the West Gate site, an infiltration rate of 0.14 in/hr (reflective of the imported soil) prescribes a 2.26 acre irrigation field. An infiltration rate of 0.02 in/hr (corresponding to the native/underlying soil) would require a field size of 15.67 acres.

[7] The volume available to store water in the soil pore spaces is referred to as Soil Water Holding Capacity (SWHC) and generally ranges from 0.8 in/ft to 2 in/ft depending on soil type. For reference, the full WQV of the West Gate Pond is equivalent to about 4 inches over the irrigation field. On an average annual basis, the system design requires that about 37 inches of captured runoff are applied over the irrigation field, before considering any direct rainfall, which amounts to an additional ~33 inches per year.

[8] In practice, performance is also dependent on the proper maintenance and function of the mechanical and electrical system components, including pumps, controls, irrigation spray heads, etc.

maintenance issues and failure mechanisms, the implication is that current ECM design criteria and the SLAT tool can easily result in facilities that do not comply with SOS rules. Therefore, SWMM was utilized to seek alternative SCM designs which could comply with the SOS rules more reliably, or which may involve facilities that are easier to maintain and less prone to failure.

Unfortunately, modern stormwater treatment SCMs do have a lower limit in terms of their ability to reduce concentrations in stormwater runoff. This understanding taken together with the modeling results from the existing system makes clear that practices which can achieve compliance with the non-degradation requirement must primarily rely on 'stormwater disposal' via infiltration (i.e. volume reduction), with load reduction via stormwater treatment in SCMs taking a secondary role. Consequently, the types of alternative designs chosen for assessment with SWMM are mostly variations on the standard R/I system (referred to below as the "Base System") or combinations with other established SCMs in use in Austin, rather than completely novel systems.

The alternative system scenarios that were evaluated using SWMM are listed and described below:

0. **Base System**, the existing West Gate R/I system described previously
1. **Base System, but gravity-drained** to the irrigation field through an orifice sized for a 72-hour drawdown (instead of pumped with a rain delay timer). Note that this type of facility is already allowed by criteria where feasible but was not modeled previously.
2. **Base System, with a biofiltration pond** positioned to capture & treat any runoff from the irrigation field. The terminal biofilter is generally designed to current ECM criteria, employs 'partial' rather than 'full' sedimentation design, 'partial infiltration' underdrain design (i.e., the underdrain outlet is not raised to create a saturated zone), is sized assuming that the drainage area is equal to the R/I system drainage area combined with the irrigation field area with an overall impervious coverage of 0% (WQV = 0.6"), and has an orifice sized for a 48-hour drawdown time.
3. **Base System, but with a partial sedimentation/sand filtration pond** in place of the retention pond. The splitter box and sand filter are sized identically to the existing retention basin. Captured runoff is pumped with a 12-hour rain delay timer to the irrigation field, just as with the Base System.
4. **System utilizing a partial sedimentation/sand filtration pond (identical to Scenario 3) pumped to an oversized biofilter**. The pump operates with an identical rain delay timer as with the Base System. The second-in-series biofilter in this case is oversized with a water quality volume of about 3.25". The biofilter employs partial sedimentation and partial infiltration. There is no irrigation field in this scenario.
5. **Base system, with an "infiltration meadow"** in place of the standard irrigation field. The infiltration meadow is defined as an irrigation field (surface area sized identically to the Base System) which is fully contained by a 12" tall berm so that any surface runoff generated within the field is forced to pond behind the berm until the ponding depth exceeds the berm overflow height. Captured runoff is pumped from the retention pond to the infiltration meadow with an identical rain delay timer as with the Base System.
    a. Same as Scenario 5 but with a 6" tall containing berm
    b. Same as Scenario 5 but with a 3" tall containing berm
    c. Same as Scenario 5 but with a 1.2" tall containing berm
    d. Same as Scenario 5 but with a 0.00" tall containing berm
6. **Same as Scenario 5, but with a partial sedimentation/sand filtration pond** in place of the retention pond
    c. Same as Scenario 6 but with a 1.2" tall containing berm
    d. Same as Scenario 6 with a 0.00" tall containing berm
7. **Same as Scenario 6, but with a "constructed wetland"** in place of the infiltration meadow. To ensure adequate ponding depth and duration, the wetland is made to be 1/10th the size (in area) of

the base system irrigation field/Scenario 5 infiltration meadow and is contained by an 18” tall berm before overflowing.

Tables 6 and 7 below provide summary results of the alternative designs modeled in SWMM. Results are presented in the same format as the Existing Conditions model results, divided into ‘quantity’ and ‘quality’ categories. Results are further distinguished between ‘Simple’ (i.e., analogous to SLAT), ‘WQV Only’, and “Overall (Including Direct Rain)’ analysis paradigms. A detailed, narrative discussion of results for each scenario is provided in the next section.

Table 6: 'Water Quantity' Results for SWMM Models of Alternative Practices

Scenario	Description	Runoff Captured (gal/yr)	Runoff Bypassed (gal/yr)	Volume Infiltrated, WQV Only (gal/yr)	Volume Infiltrated, with Direct Rainfall (gal/yr)	Site Runoff, WQV Only (gal/yr)	Site Runoff - with Direct Rainfall (gal/yr)	RCE, simple	RCE, Overall, WQV Only	RCE, Overall, including Direct Rainfall
0	Retention/Irrigation (Base)	2,280,000	253,000	1,500,000	2,410,000	389,000	1,320,000	90%	74%	65%
1	Retention/Irrigation (Base), Gravity-Drained	2,430,000	104,000	1,570,000	2,000,000	610,000	2,090,000	96%	71%	52%
2	Retention/Irrigation (Base) to Biofilter	2,280,000	253,000	1,510,000	2,460,000	363,000	1,260,000	90%	75%	67%
3	Sedimentation/Sand Filtration/Irrigation	2,280,000	253,000	1,500,000	2,410,000	389,000	1,320,000	90%	74%	65%
4	Sand Filtration Pumped to Biofiltration	2,280,000	253,000	183,000	n/a	2,020,000	n/a	90%	9%	n/a
5	Retention to Infiltration Meadow, 12" Berm	2,280,000	253,000	1,710,000	3,440,000	0.00	0.00	90%	90%	90%
5a	Retention to Infiltration Meadow, 6" Berm	2,280,000	253,000	1,710,000	3,380,000	0.00	67,100	90%	90%	87%
5b	Retention to Infiltration Meadow, 3" Berm	2,280,000	253,000	1,710,000	3,270,000	10,500	216,000	90%	89%	81%
5c	Retention to Infiltration Meadow, 1.2" Berm	2,280,000	253,000	1,530,000	3,020,000	239,000	539,000	90%	80%	68%
5d	Retention to Infiltration Meadow, 0.0" Berm	2,280,000	253,000	803,000	2,260,000	1,180,000	1,530,000	90%	43%	28%
6	Sand Filtration to Infiltration Meadow, 12" Berm	2,280,000	253,000	1,710,000	3,440,000	0.00	0.00	90%	90%	90%
6c	Sand Filtration to Infiltration Meadow, 1.2" Berm	2,280,000	253,000	1,530,000	3,020,000	239,000	539,000	90%	80%	68%
6d	Sand Filtration to Infiltration Meadow, 0.0" Berm	2,280,000	253,000	800,000	2,260,000	1,179,000	1,528,000	90%	43%	28%
7	Sand Filtration to Wetland	2,280,000	253,000	833,000	941,000	1,260,000	1,220,000	90%	39%	41%

**All gal/yr values have been rounded to three significant figures*

Table 7: ‘Water Quality’ Results for SWMM Models of Alternative Practices

Scenario	Description	TSS Load Equivalency Factors			Zn Load Equivalency Factors			Pb Load Equivalency Factors			TN Load Equivalency Factors			TP Load Equivalency Factors		
		Simple	WQV Only	Overall	Simple	WQV Only	Overall	Simple	WQV Only	Overall	Simple	WQV Only	Overall	Simple	WQV Only	Overall
0	Retention/Irrigation (Base)	0.03	0.37	0.63	0.40	0.81	1.81	0.34	0.76	1.77	0.31	0.73	1.19	0.38	0.80	1.72
1	Retention/Irrigation (Base), Gravity-Drained	0.01	0.54	0.99	0.16	0.82	2.43	0.14	0.80	2.40	0.13	0.78	1.58	0.16	0.81	2.35
2	Retention/Irrigation (Base) to Biofilter	0.03	0.08	0.20	0.40	0.78	1.72	0.34	0.87	1.70	0.31	0.66	1.15	0.38	0.69	1.46
3	Sedimentation/Sand Filtration/Irrigation	0.03	0.09	0.13	0.40	0.80	1.12	0.34	0.76	1.34	0.31	0.69	0.98	0.38	0.32	0.38
4	Sand Filtration Pumped to Biofiltration	n/a	0.30	n/a	n/a	2.52	n/a	n/a	3.27	n/a	n/a	2.27	n/a	n/a	2.12	n/a
5	Retention to Infiltration Meadow, 12" Berm	n/a	0.03	0.03	n/a	0.40	0.40	n/a	0.34	0.34	n/a	0.31	0.31	n/a	0.38	0.38
5a	Retention to Infiltration Meadow, 6" Berm	n/a	0.03	0.08	n/a	0.40	0.51	n/a	0.34	0.45	n/a	0.31	0.38	n/a	0.38	0.48
5b	Retention to Infiltration Meadow, 3" Berm	n/a	0.04	0.18	n/a	0.42	0.75	n/a	0.37	0.70	n/a	0.32	0.53	n/a	0.40	0.71
5c	Retention to Infiltration Meadow, 1.2" Berm	n/a	0.26	0.40	n/a	0.65	1.27	n/a	0.60	1.23	n/a	0.57	0.86	n/a	0.64	1.20
5d	Retention to Infiltration Meadow, 0.0" Berm	n/a	1.15	1.08	n/a	1.66	2.88	n/a	1.60	2.85	n/a	1.57	1.85	n/a	1.64	2.72
6	Sand Filtration to Infiltration Meadow, 12" Berm	n/a	0.03	0.03	n/a	0.40	0.40	n/a	0.34	0.34	n/a	0.31	0.31	n/a	0.38	0.38
6c	Sand Filtration to Infiltration Meadow, 1.2" Berm	n/a	0.07	0.09	n/a	0.65	0.84	n/a	0.69	0.96	n/a	0.54	0.72	n/a	0.59	0.74
6d	Sand Filtration to Infiltration Meadow, 0.0" Berm	n/a	0.19	0.24	n/a	1.62	1.69	n/a	2.03	1.64	n/a	1.44	1.60	n/a	1.39	1.67
7	Sand Filtration to Wetland	n/a	0.19	0.19	n/a	1.59	1.63	n/a	1.98	2.04	n/a	1.41	1.45	n/a	1.36	1.39

**LEFs for COD, E. coli, and TOC omitted for brevity*

Discussion of Results from Alternative Practices Modeling

Scenario 1: Base System, Gravity-Drained

To call this configuration an 'alternative practice' is a misnomer since gravity-flow systems are currently allowed (ECM 1.6.9.3). Regardless, it was desired to understand how a gravity-flow system would perform as compared to a pumped system since gravity-flow systems offer the benefit of avoiding complex mechanical/electrical components and high-pressure irrigation spray heads and therefore are less prone to failure and easier to maintain.

The system is modeled identically to Scenario 0 (the base system representing the existing R/I system) except that the retention basin drains to the irrigation field via an orifice sized to release the full basin volume in 72 hours (in compliance with ECM 1.6.7.A.3), instead of a pump with a rain delay timer. The model simulation applies the gravity-drained volume evenly across the irrigation field subcatchment. In practice, this requires appropriately designed flow spreader devices.

The results show that the gravity-drained system conveys captured runoff to the irrigation field more efficiently than the pumped system, which is expected given that there is no imposed delay to flows leaving the retention basin. As a result, this system bypasses about 60% less runoff and captures about 6.5% more runoff overall into the system. Considering the water quality volume only, the gravity-flow system infiltrates about the same volume as the base case (within 5%). However, when accounting for the effects of direct rainfall, the gravity-flow system infiltrates 17% less volume than the base case. For all analysis methods, the gravity-flow system produces 55-60% more site runoff (from the irrigation field, not including bypass) than the base case. Because the gravity-flow orifice allows runoff to flow freely onto the irrigation field, the soils of the irrigation field are more consistently saturated and therefore have a reduced overall capacity for infiltration. In contrast, the pumped system with rain delay timer allows the soils to dry out more in between events, so that when runoff is applied to the field the infiltration capacity is greater on average. In terms of load reduction, because of the larger discharge volumes from the irrigation field, the load reduction factors for the gravity-flow system are consistently higher compared to the base case, indicating poorer pollutant load removal.

Scenario 2: Base System, Draining to a Biofilter

Model results for the base system indicate that significant site runoff is generated from the irrigation field, which causes LEFs to be greater than 1.0. To attempt to mitigate this, a configuration which captures and treats the irrigation field runoff was created. Scenario 2 is identical to the base case, except that a biofiltration pond captures and treats any runoff from the irrigation field. The biofiltration pond is sized according to ECM criteria, assuming that the drainage area is equal to the combination of the R/I system drainage area and the irrigation field area but has an overall impervious coverage of 0%. Therefore, the pond's capture depth is 0.6", the minimum allowable in the Barton Springs Zone, and it has an orifice sized for a 48-hour drawdown time. The biofiltration pond is not lined, and so captured runoff is either infiltrated, treated and discharged through the biofiltration media and underdrains, or discharged over the pond overflow if the pond becomes full. The underdrain outlet was not modeled with an upturned outfall, so there is no saturated zone under the biofiltration media.

Results indicate that in fact, the biofiltration pond never overflows throughout the 10-year period of simulation. All captured runoff from the irrigation field it either infiltrated or filtered and discharged. The hydrologic performance is identical to the base case except that a small additional volume is infiltrated through the biofiltration pond- 0.6% more in the WQV Only analysis, and 2% more in the Direct Rainfall analysis. Overall site runoff was reduced accordingly by about 5-6% in both WQV Only and Direct Rainfall analyses. In terms of water quality performance, while the biofiltration pond removes pollutants through concentration reduction (treatment) as well as via infiltration (disposal), the overall pollutant removal performance for this scenario is not appreciably better than the base case, because hydrologic performance was only marginally better. This scenario illustrates why volume reduction methods are necessary to meet the SOS non-degradation requirements. There is a lower limit on effluent pollutant concentrations that can be achieved by SCM treatment, however when a volume of stormwater is fully infiltrated, in effect the effluent concentration is reduced to zero.

Scenario 3: Base System, with a Partial Sedimentation/Sand Filtration Pond

As in the case of Scenario 1, to call Scenario 3 an 'alternative design' is a misnomer since many existing R/I systems already include a sedimentation/sand filtration SCM in place of sedimentation-only basin ('retention pond'). Although it is not an ECM requirement, utilizing a filtration-type SCM to treat runoff before pumping to an irrigation field offers distinct benefits: better filtration of fines and debris reduces interference with pumping mechanisms and prevents clogging of irrigation spray heads, and because better pollutant removal is provided compared to sedimentation-only retention ponds, a smaller facility footprint can provide an equivalent level of treatment. This scenario was created to assess the degree of improved performance for this configuration. The model configuration is identical to the base system in all ways, except that the effluent concentrations for the first SCM in the system were set to what ECM prescribes for sedimentation/sand filtration.

As a result, the hydrologic performance is identical to the base case, in every way. The water quality performance is improved as compared to the base case. However, when accounting for direct rainfall, the LEFs for Zn, Pb, and TN still exceed 1.0.

Scenario 4: A Partial Sedimentation/Sand Filtration Pond Pumped to a Biofiltration Pond

This scenario is somewhat novel in that it includes two filtration-type SCMs in a series and does not include an infiltration field or other infiltration-based SCM. However, the second SCM in series- the biofiltration pond- is not lined, and so it can accomplish some amount of infiltration. The first half of this configuration is identical in structure to Scenario 3. The pump operates with an identical rain delay timer to convey captured runoff to the biofiltration pond. The biofiltration pond is sized to match the WQV of the sand filter above the media surface and is designed with a 2-ft ponding depth before overflow, partial sedimentation, and partial infiltration. When accounting for the storage volume attributable to the voids in the filtration media, the pond is oversized compared to what ECM would require, with a 3.25-inch capture depth relative to the developed drainage area. Because of the relatively small area of the biofiltration pond (~0.4 acres), the effect of direct rainfall was not accounted for.

Results for this scenario show that 90% less runoff is infiltrated as compared to the base case. Consequently, the volume of site runoff is more than 500% greater as compared to the base case. Pollutant load reduction is generally correlated with runoff volume reduction, and so in this case the LEFs exceed 1.0 for every pollutant, except for TSS. This result highlights the fact that while filtration-type SCMs (i.e., sedimentation/sand filtration and biofiltration) can be very effective at removal of fine particulate matter, they have a limited ability to remove other types of pollutants via treatment (i.e., concentration reduction) alone. As discussed previously, this is another illustration of why significant volume reduction (i.e., infiltration) is crucial in most cases to successfully achieve the non-degradation requirement of the SOS Ordinance.

Scenario 5: Base System, Pumped to an "Infiltration Meadow"

This scenario was designed to better contain the surface runoff generated by the infiltration field and is identical in every way to the Base Case except that the irrigation field is modeled as a storage node instead of a subcatchment, allowing runoff which is not absorbed by the soil to temporarily pond over the field. In practice, the irrigation field would be contained by a berm to create a broad, shallow ponding area which will be referred to in this study as an "infiltration meadow". Depending on the slope at the site, the infiltration meadow may be broken into several ponding areas each contained by a berm which taken together would provide the total required infiltration area. Because water is expected to pond within these basins, irrigation spray heads are not envisioned to be a necessary part of the system, and instead pumped flow from the initial SCM would be evenly distributed across the upgradient portion of the meadow area using a flow spreader or diffuser system[9].

The baseline case for this scenario was modeled with an overflow weir allowing a maximum ponding depth of 12 inches. The overflow height/maximum ponding depth was varied in subsequent sub-cases to better elucidate the model behavior: Scenario 5a sets the maximum ponding depth to 6 inches, Scenario 5b sets the maximum ponding depth to 3 inches, Scenario 5c sets the maximum ponding depth to 1.2 inches, and finally Scenario 5d sets the maximum ponding depth to 0.00 inches and so should produce equivalent results as the base case (Scenario 0).

Results for the baseline case of Scenario 5 show that the inclusion of the berm caused all the routed runoff to be infiltrated and none of it to be discharged from the infiltration meadow, both when considering the water quality volume only and when accounting for direct rainfall, hence all LEFs are well below 1.0. In Scenario 5a, with a 6-inch ponding depth, there was no discharge when considering WQV only and a small amount of discharge when accounting for direct rainfall (a volume equivalent to about 25% of the volume bypassed by the first SCM in series). The LEFs for Scenario 5a are also all below 1.0. In Scenario 5b, with a 3-inch ponding depth, there was an increased volume of site runoff both when considering WQV only and direct rainfall, but the LEFs remain less than 1.0. When the ponding depth is reduced down to 1.2 inches in Scenario 5c, the infiltration and site runoff volumes continue to increase, with the result that some of the LEFs now exceed 1.0. Scenario 5d includes a "ponding depth" of 0.00 inches, effectively removing all ponding capacity, in which case the overall volumes for infiltration and runoff approximately match the result from the base case considering direct rainfall. When considering WQV only, Scenario 5d results show a runoff volume 300% greater than the same result from the base case, and an infiltration volume about half of the result from the base case. This is explained by the fact, noted previously, that the storage node modeling approach does convey runoff to the system outfall more efficiently than the subcatchment approach, but the effect seems to become less pronounced as the overall applied volume increases.

[9] A version of this is currently allowed by the ECM, specifically for systems which are exempted from the 12-hour lag time by meeting all the following conditions: has sedimentation/sand filtration as the first SCM, gravity drains to the infiltration field, and includes berms a maximum of 6 inches high around the infiltration area- see ECM 1.6.9.3.D.1. Flow-spreading as an alternative to spray irrigation is currently allowed by the ECM if designed in accordance with ECM 1.6.7.D.

Scenarios 5, 5a, and 5b are successful because they allow for the storage and eventual infiltration of runoff which cannot be immediately infiltrated due to soil saturation, thus achieving a reduced or eliminated volume of overall site runoff. The comparison of sub-scenarios indicates that only a relatively small volume (3 inches) of additional storage capacity spread over the full infiltration area is needed to achieve enough infiltration for sufficient load reduction. To further evaluate this system's performance, overall ponding depth, frequency, and duration were analyzed. Modeled values for the infiltration meadow depth were extracted using a 10-minute reporting increment over the entire simulation period, and the data was plotted in a histogram format. Figure 9 shows the number of 10-minute reporting increments for which the modeled infiltration meadow depth was within a given range (the chosen bin width was 0.1 ft). On the abscissa, square brackets indicate a closed interval where the end point in included, whereas round parentheses indicate an open interval where the endpoint is not included.

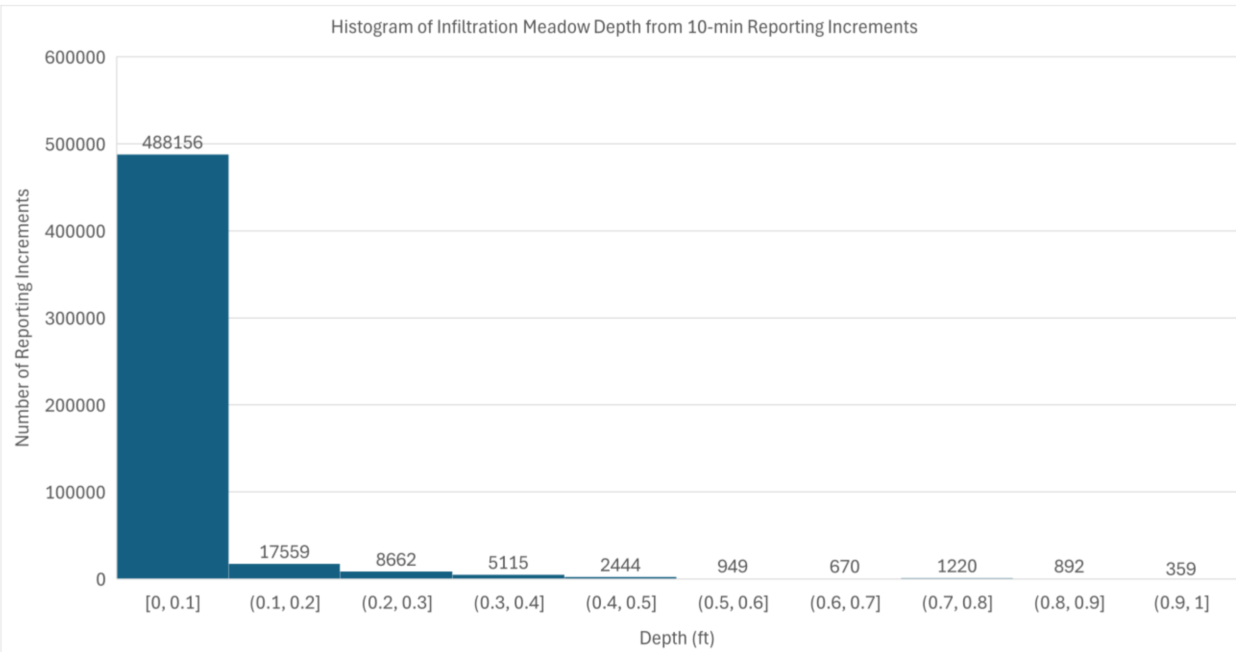

Figure 9: Histogram of Reported Depths for Infiltration Meadow with 12-inch Overflow

Figure 9 indicates that overall, the meadow predominately exhibited very shallow ponding or was dry. Over the 10-year simulation period, the infiltration meadow ponded depth was less than or equal to 1.2 inches 93% of the time, and less than or equal to six inches 99% of the time. While the infiltration meadow did not ever overflow, it was approximately full (between 0.9 and 1 ft) 0.78% of the time or 3,590 minutes (about 60 hours) during the simulation period.

One limitation of this histogram analysis is that it is based on depth results fully disaggregated from the time series and does not reflect event-based performance. In the event that the meadow did fill entirely to a ponding depth of 12 inches, a simple calculation based on the saturated soil infiltration rate of 0.02 inches per hour suggests that the drawdown time required to reach a dry condition would be 600 hours (25 days), not accounting for the effects of evaporation and/or evapotranspiration, or possible follow-on rain events. This is significantly longer than the maximum allowable ponding time of 96 hours before maintenance action is required as defined in ECM 1.6.3. However, if the 10-year period of record used for simulation is taken to be representative of a typical 10-year period in Austin, then this may only occur once or twice per decade. Figure 10, which shows a time series of the infiltration meadow depth throughout the 10-year simulation period, shows that there were only 4 events which caused the ponding depth in the infiltration meadow to exceed 6 inches.

One conclusion to draw from analysis of the time series results is that 12 inches is an unnecessarily large maximum ponding depth for this system. Scenario 5a reduces the berm height so that the maximum ponding depth in the infiltration meadow is 6 inches. Based on the infiltration rate, the drawdown time for 6 inches of ponded depth would be 300 hours or 12.5 days. Scenario 5b further reduces the berm height to 3 inches, for which the drawdown time would be 150 hours or 6.3 days. Scenario 5c models a 1.2-inch berm height, but this system was not compliant with the non-degradation standard. Figure 10 is annotated to show the maximum ponding levels modeled in scenarios 5, 5a, 5b, and 5c over the course of the simulation. Overall, the model results from Scenario 5 are promising in that they seem to indicate that even for low infiltration rate soils, only a small additional amount of runoff storage capacity is needed to achieve a volume reduction sufficient to meet treatment goals.

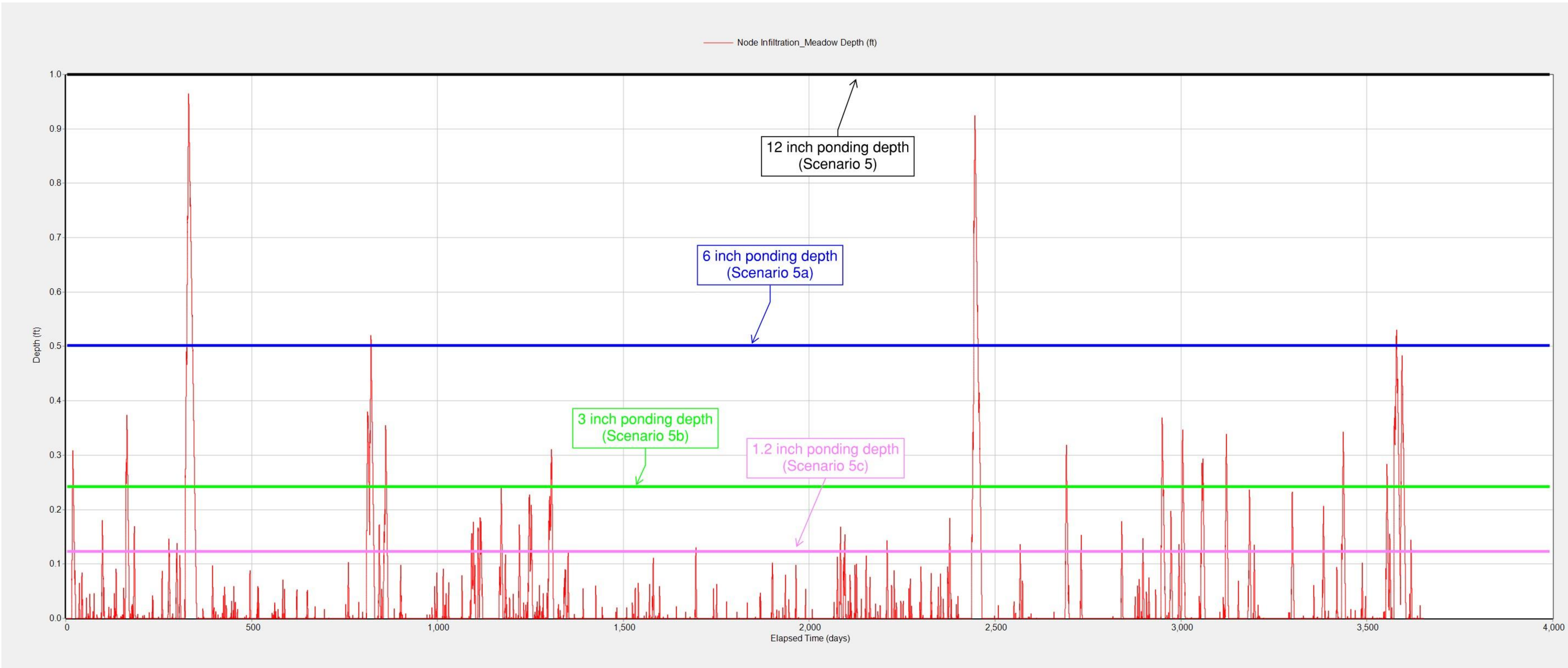

Figure 10: Time Series of Ponding Depths for Infiltration Meadow with 12-inch Overflow and Direct Rainfall (Scenario 5), Annotated to Show Ponding Depths/Overflow Levels for Scenarios 5a, 5b, and 5c

Scenario 6: Sedimentation/Sand Filtration, Pumped to an "Infiltration Meadow"

Scenario 6 is identical to Scenario 5 except that in place of retention as the first SCM in the treatment train, Scenario 6 incorporates sedimentation/sand filtration; both incorporate an "infiltration meadow" as the second SCM in the treatment train. Scenario 6 can also be viewed as being identical to Scenario 3, except for the substitution of an infiltration meadow for the irrigation field. Hydraulically, Scenarios 5 and 6 are equivalent (see Table 5), but due to the sedimentation/sand filtration process Scenario 6 provides a higher level of pollutant removal for runoff entering the infiltration meadow. However, the difference in treatment performance between Scenarios 5 and 6 is only apparent if there is discharge from the infiltration meadow. Because there is no runoff discharged from the infiltration meadow in the baseline cases of Scenarios 5 nor 6, there is no overall difference in the treatment performance. Sub-scenarios 6c and 6d were created to highlight the differences in treatment performance due to the incorporation of sedimentation/sand filtration. These scenarios mimic Scenarios 5c and 5d, with berm heights of 1.2 inches and 0.0 inches respectively and thereby maximize the volume of runoff discharged from the infiltration meadow.

As expected, hydrologically Scenario 6c is identical to 5c, just as Scenario 6d is identical to 5d. In terms of treatment performance, the incorporation of sedimentation/sand filtration provides an improvement in pollutant removal. Whereas most Scenario 5c LEFs were greater than 1.0, Scenario 6c LEFs are all less than 1.0. In comparison, Scenario 6c LEFs are equal or slightly lower than corresponding Scenario 5c LEFs for every pollutant except for lead[10]. LEFs for Scenario 6d are all greater than 1.0 indicating non-compliance with the non-degradation requirement, analogous to the results for Scenario 5d. The inclusion of a sand filter allows for the minimum storage depth required to achieve the non-degradation standard to be reduced by more than 50%, from 3 inches (as in Scenario 5b) to 1.2 inches. In addition to this advantage, there would be other operational benefits to utilizing sand filtration especially when the system includes pumps, pipes, diffusers, or other components prone to clogging with debris.

Scenario 7: Sedimentation/Sand Filtration, Pumped to a Constructed Wetland

Inspired by the potential for very long drawdown times as in Scenario 5, Scenario 7 was created to understand the potential performance of a system incorporating an intentionally constructed wetland. Scenario 7 is identical to Scenario 6 except that instead of an infiltration meadow, a constructed wetland is incorporated by reducing the size of the facility to 1/10th the size of the infiltration meadow in Scenarios 5 and 6, and also by increasing the height of the containing berm to 18 inches. The native soil infiltration rate was assumed to remain the same as in all other modeled scenarios, 0.02 inch/hour. A statistical analysis of ponding depth over the course of the simulation shows that the constructed wetland has a ponded depth less than 1.2 inches 26% of the time on average. The ponding depth is greater than or equal to 6 inches 60% of the time, and greater or equal to 12 inches 42% of the time. Figure 11 is a histogram of the number of 10-minute reporting increments for which the modeled depth was within a given range.

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[10] The weighted average concentration of lead leaving the infiltration meadow after the sand filter is greater than the same weighted average concentration for the infiltration meadow after the retention pond. This is because Scenarios 5c, 5d, 6c, and 6d model the "infiltration meadow" effluent concentrations according to ECM irrigation field effluent due to their shallow depths, rather than ECM "retention pond" effluent as in Scenarios 5, 5a, 5b, 6, 6a, and 6b. Per the ECM, irrigation field effluent concentrations for all pollutants are lower than sand filtration effluent concentrations except for the case of lead.

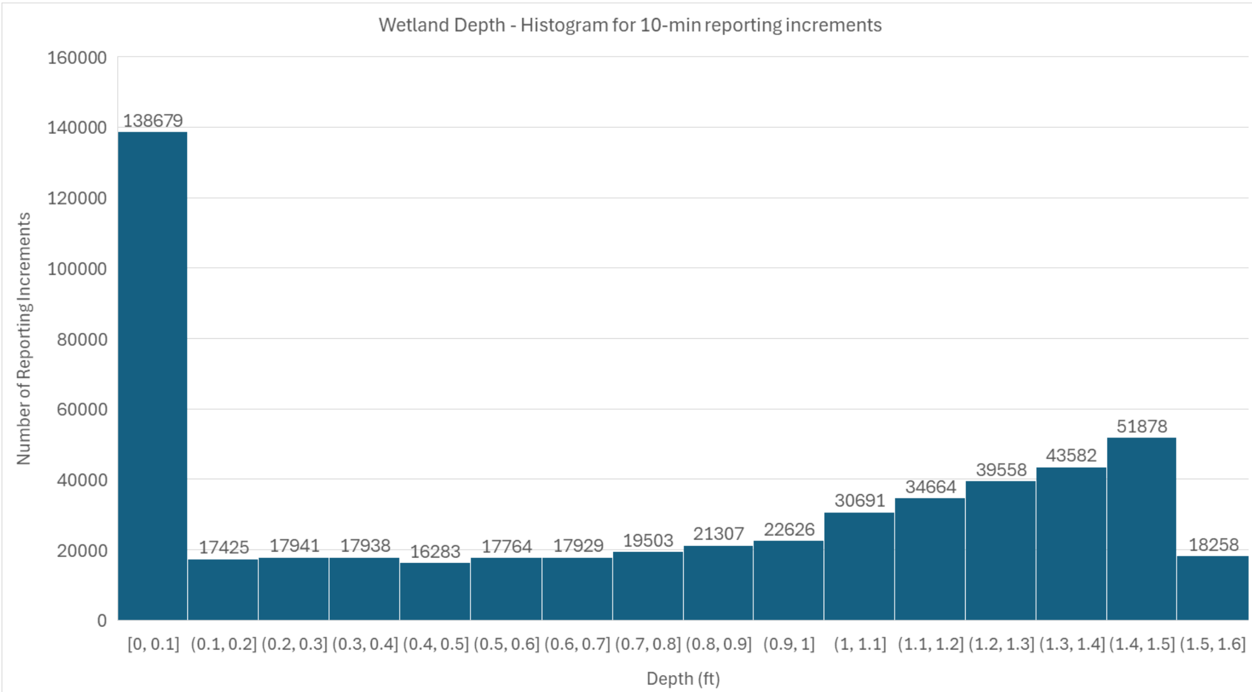

Figure 11: Histogram of Reported Depths for Constructed Wetland with 18-inch Overflow

Hydrologically, the results show that much less volume is infiltrated (50% or less) as compared to the Base Case. The system discharges a similar volume of site runoff (when considering direct rainfall) as the Base Case. As a result, the treatment results show LEFs greater than 1.0 for every pollutant summarized in Table 6 except total suspended solids. This system does not meet the non-degradation requirement, which is unsurprising given the small area and correspondingly low capacity for infiltration. Note that due to a lack of better available data, the effluent concentrations from the constructed wetland are modeled using ECM retention pond effluent concentrations. LEF results are dependent on effluent concentration definitions, and so if new data specific to constructed wetland effluent concentrations becomes available, the results could change.

Summary of Alternative Designs Modeling

Seven different types of alternative treatment practices to standard R/I systems were modeled using SWMM, including variations on two types of systems resulting in thirteen total scenarios. As expected, the systems which do not facilitate significant infiltration of captured stormwater failed to meet the SOS non-degradation standard, which requires the total pollutant load leaving a developed site to not exceed the pre-development load for each of the regulated pollutants. The modeled systems included a gravity-drained version of the existing West Gate pond system (with no pump or rain delay), a version of the West Gate pond with a sedimentation/sand filtration pond instead of a retention pond, a system which added a biofiltration pond to receive and treat effluent from the existing system, a system simply employing a treatment train of a sedimentation/sand filtration pond followed by an oversized biofiltration pond, and a treatment train employing a sedimentation/sand filtration pond followed by a constructed wetland. None of these systems were able to achieve load equivalency factors less than 1.0 for all pollutants under the most physically accurate 'Overall' analysis method which accounts for direct rainfall on the irrigation fields.

The two types of systems which were able to achieve load equivalency factors less than 1.0 are those which incorporate berms on the irrigation field, in which cases the irrigation field is referred to as an 'infiltration meadow'. The pollutant reduction of such systems which included sedimentation/filtration as the first SCM in series was improved compared to those which included retention ponds, allowing for a shorter effective berm height to achieve LEFs less than 1.0. The overall success of these systems can be attributed to the provision of additional storage for runoff on top of the irrigation field, thereby lengthening the period of time during which infiltration can occur and facilitating an overall larger infiltration volume and a smaller discharge volume as compared to systems which do not provide any berms on the irrigation field. It was found that by incorporating sedimentation/sand filtration and providing a total storage volume equivalent to only 1.2 inches over the irrigation field using berms, compliance with the non-degradation standard could be achieved. In practice, while meeting this criterion the designer would need to choose the height and layout of the berms to best fit the irrigation field slope, shape, and infiltration rate unique to each site.

Discussion

Discussion of Recommended Revisions to Design Criteria

As implied by the modeling analyses conducted comparing SLAT and SWMM, as well as from the analysis of inspection records and pond inspector observations, improvements are needed to consistently achieve high retention/irrigation system compliance rates, less burdensome system maintenance requirements, and improved pollutant load reductions to meet the standards of the SOS Ordinance. To this end, revisions are recommended to the City of Austin criteria concerning design requirements for retention/irrigation systems, as well as to the sections describing technical guidance for compliance with the SOS rules, general maintenance and construction requirements, and standards for infiltration rate evaluation.

Infiltration Rate Evaluation Requirements

ECM section 1.6.7.4 describes the requirements for establishment of the design infiltration rate for any water quality control which incorporates infiltration. The first suggested revision is to require retention/irrigation system designers to complete in-situ testing to establish the infiltration rate. Currently, designers are only required to complete desktop study and field sampling (i.e. soil sampling for textural and laboratory analysis) as a basis for the establishment of a design infiltration rate for irrigation fields. However, given the critical importance of infiltration rate to the performance of irrigation fields, it is recommended that the most accurate level of infiltration rate investigation be completed by retention/irrigation system designers. In-situ testing is significantly more accurate than field sampling because it allows for infiltration rates of the native soil profile to be directly measured.

The second recommended revision to the infiltration rate evaluation criteria is to require a more formal reporting and documentation of infiltration rate evaluation activities, and to ensure that the design infiltration rate is established under the supervision of a licensed professional engineer. Anecdotally, inspectors have communicated that often the submitted design infiltration rate for a given irrigation site is not representative of the actual conditions but instead overestimates the true value. The result of this is that the system tends to under-perform, creating excessive runoff from the irrigation field. The standard of professional practice needs to be elevated, and one way to achieve this is by requiring more explicit documentation of testing, mapping, and calculations, and submittal of a report under seal which outlines the basis of the infiltration design.

One further revision to criteria which was considered but is not recommended at this time is to raise the required minimum factor of safety from 2 to 3 or higher. While there is a basis in the literature for utilizing higher factors of safety to establish design infiltration rates for infiltration-based water quality controls (Philips and Kitsch 2011), it is recommended to first pursue improvements to the testing and measurement methodology. The study results demonstrate that when an adequate infiltration rate exists on the site, retention/irrigation systems can achieve compliance with the non-degradation requirement. The key is that systems are designed and sized according to a realistic infiltration rate for the site. If adoption of more rigorous in-situ testing methods combined with other design changes as described below continue to result in performance issues, then a revision to increase the minimum required factor of safety may be warranted as a next step.

Design Criteria for Retention/Irrigation Systems

Most of the revisions recommended by this study can be implemented in ECM Section 1.6.7.A, which contains retention/irrigation system design criteria. The first recommended change to this section will be to require in all cases a sedimentation/sand filtration SCM instead of retention as the first control in series. Modeling results demonstrated a higher level of pollutant removal by sedimentation/sand filtration/irrigation systems with berms as compared to retention/irrigation, allowing for more efficient compliance with the non-degradation requirement. Utilizing sedimentation/sand filtration, an effective berm height of only 1.2 inches was needed to achieve compliance in the model, whereas a berm height of at least 3 inches was needed when retention was the first control in series. In addition, inspector observations support the preference for sedimentation/sand filtration due to the better filtration of solids from captured stormwater, resulting in less wear on mechanical components and less frequent clogging in pump and pipe systems associated with the irrigation field. Consequently, if sedimentation/sand filtration is required in place of retention, then the title of ECM section 1.6.7.A should be changed accordingly. The recommended new name for the overall treatment practice is 'sedimentation/sand filtration/infiltration', emphasizing infiltration as the key treatment process at work in the irrigation fields.

Inspection records show that high pressure irrigation system components, including broken and/or clogged pipes and sprinkler heads, were the most common point of failure in non-compliant inspections. The need to intensively mow irrigation fields to provide access to heads for inspections and repairs, which often damages the equipment itself, contributes to these failures. Inspectors also report that the spray irrigation system components require a high level of maintenance effort, attention, and cost to ensure proper functioning over time, as described previously in this report. To eliminate this type of system failure, we recommend replacing spray irrigation systems with level flow spreaders as the primary method used to apply captured stormwater runoff to irrigation fields. Combined with constructed terraces or earthen berms on contours down the irrigation field slope, appropriately designed flow spreaders will accomplish an even distribution of captured runoff for infiltration into the site soils and are compatible with both gravity-drained systems and systems which may require a low-head pump to move the captured stormwater to the top of the irrigation field. An ancillary benefit of a flow spreader and berm system is that irrigation areas will not need to be mowed as intensively, since they will no longer contain critical system components that are likely to break and must be accessed frequently for inspection and repair. Berms and terraces can be allowed to revegetate to a much more natural condition while still performing their flow spreading and infiltration functions. In general, flow spreader systems will have low Total Dynamic Head (TDH) and low-pressure pumps (such as wastewater effluent, trash, or grinder pumps) are an appropriate option, however, there may be some designs with a higher TDH due to lift (pumping to high elevations) that may require a well submersible pump. When used for stormwater, these low-pressure pumps should have fewer issues and last longer than high-pressure pumps, reducing cost of long-term cost of maintenance, repair, and replacement.

State-of-the-practice level spreader designs incorporate multiple system components to ensure even distribution of the applied volume, avoid flow concentration, and facilitate maintenance. An inner perforated pipe, typically two to three inches in diameter, carries pumped or gravity-drained flow from the pond and contains perforations that are sized and spaced to ensure approximately equal head pressure, and therefore flow, at each discharge point. Typically, the inner perforated pipe will have a consistent hole diameter with variable hole spacing to balance head losses down the pipe and will be installed with a constant elevation along its run. The inner pipe is installed inside a sleeve pipe, typically six inches in diameter and possessing a regular perforation pattern. The dual pipe assembly is laid or installed inside either an above-ground rock gabion structure or below ground in a rock-filled trench. In an above-ground installation, the inner pipe in installed such that it may be pulled for maintenance purposes without disturbance of the outer sleeve which is embedded in the gabion. With below-ground or trench installations, mid-run pipe cleanouts are provided to facilitate jet flushing for cleaning or clog removal.

As demonstrated by the modeling results, using earthen berms or terraces to capture surface runoff and provide a small amount of storage volume on the irrigation field can increase pollutant removal and facilitate compliance with the non-degradation standard of the SOS ordinance. When utilizing a sedimentation/sand filtration SCM first in series, an additional storage volume equivalent to 1.2 inches over the irrigation field was needed for the model system to achieve compliance. Based on these results, we recommend adding criteria to require a berm or terrace layout on all irrigation fields which collectively stores a runoff volume equivalent to 1.2 inches over the pre-determined irrigation field area. The criteria should include requirements for berm geometry (i.e., side slopes, top width, maximum height), overflow, freeboard, erosion prevention, and construction practices, but should also allow designers enough flexibility to be compatible with a wide range of site conditions and minimize disturbance to intact natural areas. We recommend providing guidance for choosing the two key design variables of berm height and berm spacing, which in general will depend on the field length in the downslope direction, the field average slope, and the design infiltration rate. Generally, steeper-sloped fields will require taller, more closely spaced berms than flatter fields to achieve the same storage volume. Fields with slower infiltration rates should avoid taller berms which may result in very long ponding times and stagnant water issues. Ultimately, however the berms are laid out, the designer should be required to prove that the equivalent total storage volume of 1.2 inches over the field area is provided via submitted calculations or a stage-storage table in the construction drawings.

Miscellaneous Revisions

In addition to the revisions discussed above, additional revisions are recommended to related sections of the environmental criteria manual and review to ensure consistency. For example; the part of ECM 1.6.3 which pertains to major maintenance requirements for retention/irrigation systems should be revised to reflect the updated name of the treatment practice, the decreased need for intensive mowing in irrigation areas, and the replacement of irrigation spray heads with flow spreaders and berms. The inspection and maintenance requirements for gravity-drained systems should be described in this section as distinct from those of pumped systems. Requiring less frequent maintenance and inspection for gravity-drained systems may be appropriate given the absence of failure-prone mechanical/electrical equipment and may serve to further incentivize the development of these types of systems. In addition, ECM section 1.6.9 should be revised for consistency with the updated name of the 1.6.7.A treatment practice, and to reflect the replacement of irrigation spray heads with flow spreaders and berms.

Finally, a search should be conducted through the Environmental Criteria Manual (ECM) and the Drainage Criteria Manual (DCM) for any references to retention/irrigation, and the language should be revised for consistency with updated nomenclature and any pertinent design criteria changes. These sections may include but are not limited to: ECM 1.2.2.1 Submittal Requirements for Projects in the Barton Springs Zone, ECM 2.4.9.1 Requirements for Landscaped Areas, ECM 1.6.2 General Design Guidelines, ECM Appendix R-5 Retention/Irrigation Pond Calculations, ECM Appendix V Figures 1-3 Operating Permit Flowcharts, and DCM 1.2.4.E.11 Mechanical SCMs.

Conclusions

Inspection records demonstrate that retention/irrigation stormwater treatment systems consistently fail to comply with the non-degradation requirement of the Save Our Springs Ordinance in Article 13 of the Land Development Code. This report indicates that non-compliance stems from weaknesses in design guidelines which lead to performance and maintenance issues, and therefore it is imperative to revise design criteria. The most common problems noted in inspection records of existing contemporary systems originate from high-pressure spray irrigation that inherently requires pumps, panels, and irrigation pipes/spray heads which all have various vulnerabilities. In addition, the modeling investigations herein demonstrate the inadequacy of current design criteria which do not ensure accurate estimation of infiltration rates and sufficient volume reduction through infiltration. These results suggest that failure rates can be significantly reduced and compliance with the non-degradation requirement of SOS can be accomplished by targeted modifications to design criteria as described in the recommendations section below.

Recommendations

Revisions to the design criteria for retention/irrigation stormwater controls could improve the effectiveness and reliability of systems and ensure their compliance with the non-degradation standard of the SOS ordinance primarily through improving infiltration performance while also lowering the long-term cost of maintenance, as described in the discussion sections of this report. An increase to the factor of safety was considered as a general strategy to improve outcomes, however, it was determined that it would be unnecessary and would not necessarily improve non-compliance as much as the other strategic recommendations. Recommended revisions to sections ECM 1.6.3, 1.6.7, 1.6.9 and others include:

- Require in-situ infiltration rate testing for all systems
- Require more rigorous documentation of infiltration testing methods and results
- Require sedimentation/sand filtration/infiltration to replace retention/irrigation for all systems in the Barton Springs Zone
- Prohibit high-pressure sprinkler spray application and instead require lower-pressure flow spreader application for captured stormwater
- Encourage gravity-drained systems in favor of pumped systems whenever possible
- Require berms to be constructed downslope of stormwater application to enhance infiltration
- Replace the name ‘Retention-Irrigation’ with ‘Sedimentation-Filtration-Infiltration’ and ensure consistency with nomenclature throughout criteria

Acknowledgments

We extend our appreciation to the leadership within Austin Watershed Protection for fostering collaboration between work groups. This support has enabled a solution-focused effort, fueled by communication throughout the chain of command. We also thank the development community and other professionals who routinely adjust their design and planning approaches to comply with criteria manuals as rules improve over time resulting in responsible stewardship of our shared natural resources.

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Appendix A

West Gate R/I Pond Google Earth Aerial Image Dates, Retention Basis Status, and Antecedent Rain Condition (See Figure 8)

Date	Retention basin status	Days since last rain	Antecedent rain date and amount
2012 Aug 2	total inundation	18	July 15th (1.77”)
2013 Jul 19	total inundation	1	July 14 – 18th (3.34” total)
2013 Oct 6	total inundation	0	September 29th (1.9”) and October 6th (0.23”)
2013 Nov 1	total inundation	1	October 31st (1.25”)
2014 Oct 3	dry	15	September 18th (3.63” and 0.44”)
2014 Dec 25	dry	6	December 19th (0.49”)
2015 May 29	total inundation	0	May 25th (0.25”), May 27th (0.73”), May 29th (0.25”)
2015 Jul 14	total inundation	14	June 30th (0.15” and 0.16”)
2016 Feb 4	total inundation	9	January 26th (1.04”)
2016 Mar 16	total inundation	4	March 8th – 12th (2.75” total)
2017 Jan 8	total inundation	6	January 2nd (0.39”)
2017 Feb 25	total inundation	5	February 19th - 20th (1.18” total)
2018 Jan 14	partial inundation	26	December 19th (1.64”)
2019 Nov 23	total inundation	30	October 24th (2.87”)
2020 Mar 25	total inundation	4	March 21st (0.85”)
2020 Apr 16	total inundation	7	April 9th (0.24”)
2021 Mar 26	total inundation	1	March 23rd (0.58”) and March 25th (0.22”)
2021 Jun 18	partial inundation	15	June 3rd (1.55” total)
2022 Jan 16	partial inundation	28	December 18th – 19th (0.64” total)
2022 Mar 26	partial inundation	4	March 21st – 22nd (1.41”)
2022 Jul 6	dry	8	June 27th – 28th (1.22”)
2023 Jun 11	total inundation	1	June 10th (0.80”)
2023 Nov 26	dry	13	November 9th – 13th (1.06”)
2024 Mar 2	partial inundation	21	February 10th (1.41”)
2024 Oct 27	partial inundation	9	October 18th (0.02”) September 2-5th (0.35”)
2025 Mar 14	total inundation	10	March 4th (0.2”)

Appendix B

Selected Applicable Sheets from the West Gate R/I Pond Construction Site Plan (SPL-SP-2008-0534D)

SUBMITTAL PREPARED BY:

ENGINEERING SERVICES DIVISION

CITY OF AUSTIN
PUBLIC WORKS DEPARTMENT
ENGINEERING SERVICES DIVISION

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ENGINEERING · CITY OF AUSTIN · FOUNDED 1839 · DESIGN

STATE OF TEXAS · ADEWALE K. ODUFUYE · 91302 · LICENSED · PROFESSIONAL ENGINEER

7/16/09

THE SEAL APPEARING ON THIS DOCUMENT WAS AUTHORIZED BY ADEWALE K. ODUFUYE, P.E., LIC.# 91302

PLANS OF PROPOSED
WEST GATE BOULEVARD EXTENSION
FROM COHOBA DRIVE TO CAMERON LOOP

F.D.U. No. 8071-6207-9056
C.I.P ID No. 7400.001

9/1/09
PROJECT ENGINEER - ADEWALE K. ODUFUYE, P.E. — DATE

APPROVED BY:

9/1/09
for PUBLIC WORKS DEPARTMENT - CHIEF ENGINEER — DATE

9-4-09
PROJECT SPONSOR — DATE

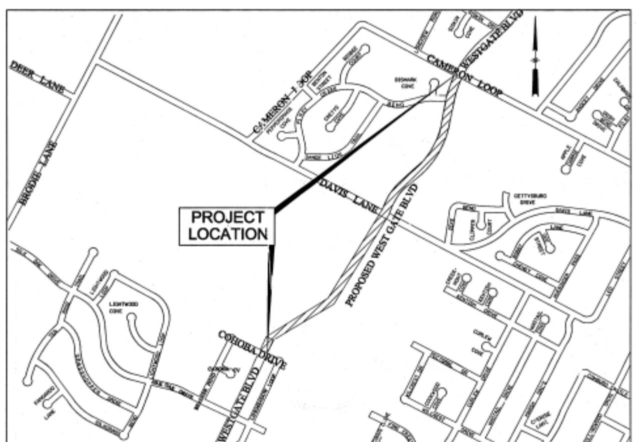
CENTER LINE RADIUS WAS APPROVED BY AUSTIN TRANSPORTATION DEPARTMENT IN LETTER DATE SEPTEMBER 4TH, 2009

1c: (C) 1, 2, (Replaced) 8-11, 14, 26-34, 46-47, 80, 81, 84, 87-91, 118, 127, 128, 150-154

2c: (C) 1, 2, 25, 46, 57, 62, 70, 71, 76-83, (R) 111, (C) 114, 117 (R) 135 (C) 137 (A) 139-142

CORRECTIONS RECORD

NO.	DESCRIPTION	BY	REVISE (R) ADD (D) VOID (V) SHEET NO.'s	TOTAL # SHEETS IN CORRECTION PLAN SET	NET CHANGE IMP. COVER (sq.ft.)	TOTAL SITE IMP. COVER (sq.ft.)/%	CITY OF AUSTIN APPROVAL DATE	DATE IMAGED
1c	REMOVE DUPLICATE LABELS ADD REVEGETATION NOTE		SEE SHEET 2	138	-0-			1.06.2010
2c	CHANGE POND 1 CHANGE POND 2 ADD STRUCTURE DETAILS		SEE SHEET 2	142	-0-			9.15.2010
3c	Revise [illegible]		(R) 2, 9, 10, 11, 47	142				[illegible]



MAPCO PG. 642-643 GRID(E16) — LOCATION MAP — N.T.S.

AUSTIN WATER UTILITY EXPIRATION DATE ... 2010

REVIEWED BY THE AUSTIN WATER UTILITY APPLIES ONLY TO FACILITIES WITHIN PUBLIC STREETS OR PUBLIC UTILITY EASEMENTS. ALL OTHER WATER AND WASTEWATER FACILITIES INSIDE PRIVATE PROPERTY ARE UNDER THE JURISDICTION OF BUILDING INSPECTION.

ALL RESPONSIBILITY FOR THE ADEQUACY OF THESE PLANS REMAINS WITH THE ENGINEER. APPROVAL OF THESE PLANS BY THE CITY OF AUSTIN DOES NOT REMOVE THESE RESPONSIBILITIES.

Inspection Notice:
Please contact Public Works, Construction Inspection Division at 974-7567 for arrangements for payment of inspection fees and job assignment for inspection of the public utilities related to this site. Inspection fees must be paid before any pre-construction meeting can be held.

ALL IMPROVEMENTS SHALL BE MADE IN ACCORDANCE WITH THE RELEASED SITE PLAN. ANY ADDITIONAL IMPROVEMENTS WILL REQUIRE SITE PLAN AMENDMENT AND APPROVAL OF THE WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT.

THIS PROJECT IS LOCATED WITHIN THE SOUTH BOGGY CREEK WATERSHED CLASSIFIED AS SUBURBAN AND THE SLAUGHTER CREEK WATERSHED CLASSIFIED AS THE BARTON SPRINGS ZONE.

THE 100 YEAR FLOOD PLAIN IS CONTAINED WITHIN DRAINAGE EASEMENT(S) SHOWN ON PLAN.

A PORTION OF THIS TRACT IS WITHIN THE BOUNDARIES OF THE 100 YEAR FLOOD PLAIN OF ANY WATERWAY THAT IS WITHIN THE LIMITS OF STUDY OF THE FEDERAL FLOOD INSURANCE ADMINISTRATION (FIRM). PANEL 170 OF 410 AS PER FEMA MAP NUMBER D48453C0580H DATED SEPTEMBER 26, 2008

THE SITE IS NOT LOCATED IN THE EDWARD'S AQUIFER RECHARGE ZONE

THIS PROJECT IS NOT EXEMPT FROM THE WATERSHED PROTECTION REGULATIONS (CHAPTERS 25-2 AND 25-8 OF THE LDC)

AN ADMINISTRATIVE VARIANCE WAS GRANTED PER SECTION 25-8-42(B)(6) OF THE LDC FOR CUT ASSOCIATED WITH THE WATER QUALITY AND DETENTION UP TO 11 FEET.

[redacted] BY:

11/18/2009
FOR WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT — DATE

SP-2008-0534D
SITE PLAN/DEVELOPMENT PERMIT NUMBER — DATE

07/21/2009
AUSTIN WATER UTILITY — DATE

APPROVED 1c KA JAN 06 2010 CITY OF AUSTIN WATER DEVELOPMENT SERVICES

APPROVED 2c KA SEP 15 2010 CITY OF AUSTIN WPDR DEVELOPMENT SERVICES

PRESSURE ZONE(S)	SOUTHWEST A
CALCULATED PRESSURE @ HIGHEST LOT	71 PSI
CALCULATED PRESSURE @ LOWEST LOT	91 PSI

W-2009-0046
SP-2008-0534D

1 OF 138

WEST GATE BOULEVARD EXTENSION FROM COHOBA DRIVE TO CAMERON LOOP

N:\Team3\West_Gate_Extension\DGN\WEST_GN_COV_20.dgn

INDEX OF SHEETS

1	COVER SHEET	50	ROADWAY CROSS SECTIONS STA. 6+00 - STA. 8+50	99	CONDUIT STANDARD NOTES AND DETAILS SHEET 2
2	INDEX OF SHEETS	51	ROADWAY CROSS SECTIONS STA. 9+00 - STA. 12+50	100	TEMPORARY TRAFFIC CONTROL PLAN SHEET 1
3	GENERAL NOTES	52	ROADWAY CROSS SECTIONS STA. 13+00 - STA. 16+50	101	TEMPORARY TRAFFIC CONTROL PLAN SHEET 2
4	LEGEND	53	ROADWAY CROSS SECTIONS STA. 17+00 - STA. 19+50	102	TEMPORARY TRAFFIC CONTROL PLAN SHEET 3
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8	EXISTING DRAINAGE AREA MAP & CALCULATIONS (REPLACED SHEETS 1)	57	ROADWAY CROSS SECTIONS STA. 28+53.32 - STA. 30+50	106	ROADWAY - STANDARD DETAILS SHEET 1
9	PROPOSED DRAINAGE AREA MAP & CALCULATIONS COHOBA DR. STA. 16+00	58	ABANDON EXISTING 8" A.C. 8" WATER LINE PLAN & PROFILE STA. 14+97.73 - STA. 18+50	107	ROADWAY - STANDARD DETAILS SHEET 2
10	PROPOSED DRAINAGE AREA MAP & CALCULATIONS STA. 16+00 - CAMERON LOOP	59	ABANDON EXISTING 8" A.C. WATER LINE PLAN & PROFILE STA. 18+50 - STA. 22+50	108	ROADWAY - STANDARD DETAILS SHEET 3
11	ONSITE DRAINAGE AND INLET CALCULATIONS	60	ABANDON EXISTING A.C. 8" WATER LINE PLAN & PROFILE STA. 22+50 - STA. 26+50	109	ROADWAY - STANDARD DETAILS SHEET 4
12	EROSION/SEDIMENTATION CONTROL NOTES AND DETAILS	61	ABANDON EXISTING A.C. 8" WATER LINE PLAN & PROFILE STA. 26+50 - STA. 28+34.00	110	ROADWAY - STANDARD DETAILS SHEET 5
13	TREE PROTECTION NOTES AND DETAILS	62	STORM DRAIN PLAN & PROFILE - P-66 & P-67 STA 0+00 - 2+20	111	TXDOT - CONCRETE WINGWALLS WITH PARALLEL FOR SKEWED & NON-SKEWED DETAILS
~~13A~~	~~SLOPE MAP~~ SEE SHEET 136	63	STORM DRAIN PLAN & PROFILE - P61, P62 & P65	~~111A~~	~~TXDOT - SINGLE BOX CULVERTS PRECAST 4'-0" SPAN SCP-4~~ SEE SHEET 135
~~13B~~	~~PROPOSED GRADING PLAN - WEST GATE BLVD~~ SEE SHEET 137	64	STORM DRAIN PLAN & PROFILE STA. 2+20 - STA. 3+50	112	LIMESTONE & CANTILIVER RETAINING WALL DETAILS
~~13C~~	~~PROPOSED STAGING AREA~~ SEE SHEET 138	65	STORM DRAIN PLAN & PROFILE STA. 3+50 - STA. 7+50	113	DRAINAGE - STANDARD DETAILS SHEET 1
14	TREE LIST AND TREE MITIGATION	66	STORM DRAIN PLAN & PROFILE STA. 7+50 - STA. 11+50	114	DRAINAGE - STANDARD DETAILS SHEET 2
15	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 0+00 - 4+00	67	STORM DRAIN PLAN & PROFILE STA. 11+50 - STA. 15+50	115	DRAINAGE - STANDARD DETAILS SHEET 3
16	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 4+00 - 8+00	68	STORM DRAIN PLAN & PROFILE STA. 19+50 - STA. 23+50	116	DRAINAGE - STANDARD DETAILS SHEET 4
17	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 8+00 - 12+00	69	STORM DRAIN PLAN & PROFILE STA. 23+50 - STA. 27+50	117	DRAINAGE - MODIFIED INLETS
18	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 12+00 - 16+00	70	STORM DRAIN PLAN & PROFILE STA. 27+50 - STA. 30+45	118	DRAINAGE - WATER QUALITY POND DETAILS
19	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN- DAVIS LANE	71	STORM DRAIN PLAN & PROFILE P1-1(4'X3' BC) AND P1-2(4'X3' BC)	119	WATER - STANDARD DETAILS SHEET
20	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 16+00 - 20+00	72	STORM DRAIN PLAN & PROFILE P3-3 & P3-2 (24"), P3-5 AND P3-7(18" RCP)	120	TRAFFIC CONTROL - LANE CLOSURES, SIDEWALK CLOSURES & SHIFTING TRAFFIC
21	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 20+00 - 24+00	73	STORM DRAIN PLAN & PROFILE P3-9(18" RCP)	121	TRAFFIC CONTROL - DETOURS & FLAGGING OPERATIONS
22	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 24+00 - 28+00	74	STORM DRAIN PLAN & PROFILE P2-10(18" RCP), P2-13 (24")	122	TRAFFIC CONTROL - PAVEMENT MARKING
23	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN STA. 28+00 - 30+45 & POND 1	75	STORM DRAIN PLAN & PROFILE P2-8, P2-6, P2-3 AND P2-4(18" RCP)	123	TRAFFIC CONTROL - WORK AREA PROTECTION
24	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN RETENTION & IRRIGATION POND 2- SHEET 1	76	DRAINAGE - WATER QUALITY POND & DETENTON POND 1 CALCULATIONS	124	TRAFFIC CONTROL - TEMPORARY TRAFFIC CONTROL DEVICES
25	EROSION/SEDIMENTATION CONTROL AND TREE PROTECTION PLAN RETENTION & IRRIGATION POND 2- SHEET 2	77	DRAINAGE - WATER QUALITY & DETENTION POND 1 DETAILS	125	TRAFFIC CONTROL - TEMPORARY TRAFFIC CONTROL DEVICES
26	PROPOSED LANDSCAPING PLAN STA. 0+00 - 4+00	78	DRAINAGE - WATER QUALITY POND & DETENTION POND 1 CROSS SECTIONS	126	TRAFFIC CONTROL - SPECIAL TRAFFIC CONTROL DETAILS
27	PROPOSED LANDSCAPING PLAN STA. 4+00 - 8+00	79	NORTH DIVERSION BOX DETAIL (POND 1)	127	IRRIGATION DETAILS
28	PROPOSED LANDSCAPING PLAN STA. 8+00 - 12+00	80	DRAINAGE - RETENTION & DETENTION POND 2- CALCULATIONS	128	LIFT STATION DETAILS (TYP)
29	PROPOSED LANDSCAPING PLAN STA. 12+00 - 16+00	81	DRAINAGE - RETENTION / DETENTION POND 2 DETAILS	129	ELECTRICAL SITE PLAN, ONE- LINE DIAGRAM AND DETAILS
30	PROPOSED LANDSCAPING PLAN- DAVIS LANE	82	DRAINAGE - RETENTION & DETENTION POND 2 CROSS SECTION	130	ELECTRICAL NOTES, SYMBOLS AND ABBREVIATIONS
31	PROPOSED LANDSCAPING PLAN STA. 16+00 - 20+00	83	SOUTH DIVERSION BOX DETAIL (POND 2)	131	ELECTRICAL DETAILS
32	PROPOSED LANDSCAPING PLAN STA. 20+00 - 24+00	84	POND 2 - GRADING PLAN (CAS)	132	SPRINKLER PATTERN
33	PROPOSED LANDSCAPING PLAN STA. 24+00 - 28+00	~~84A~~	~~POND 2 - SPRINKLER PATTERN (CAS)~~ SEE SHEET 132	133	BY-PASS DRAINAGE DITCH PLAN & PROFILE
34	PROPOSED LANDSCAPING PLAN STA. 28+00 - 30+45	~~84B~~	~~POND 2 - BY PASS DRAINAGE DITCH PLAN & PROFILE (CAS)~~ SEE SHEET 133	134	IRRIGATION SYSTEM PLAN
35	ROADWAY TYPICAL CROSS SECTIONS	~~84C~~	~~POND 2 - IRRIGATION SYSTEM PLAN (CAS)~~ SEE SHEET 134	135	TXDOT - SINGLE BOX CULVERTS PRECAST 4'-0" SPAN SCP-4
36	BORING LOGS MAP	85	POND 1 - LANDSCAPING PLAN (COLEMAN & ASSC.)	136	SLOPE MAP
37	BORING LOGS 1-6	86	POND 1 - LANDSCAPING DETAILS (COLEMAN &ASSC.)	137	PROPOSED GRADING PLAN - WEST GATE BLVD
38	BORING LOGS 7, 8 & 10	87	PAVEMENT MARKING / STRIPING PLAN STA 0+00 - STA 8+00	138	PROPOSED STAGING AREA
39	ROADWAY PLAN & PROFILE STA. 0+00 - 4+00	88	PAVEMENT MARKING / STRIPING PLAN STA 8+00 - STA 16+00		
40	ROADWAY PLAN & PROFILE STA. 4+00 - 8+00	89	PAVEMENT MARKING / STRIPING PLAN DAVIS LANE		
41	ROADWAY PLAN & PROFILE STA. 8+00 - 12+00	90	PAVEMENT MARKING / STRIPING PLAN STA 16+00 - STA 24+00		
42	ROADWAY PLAN & PROFILE STA. 12+00 - 16+00	91	PAVEMENT MARKING / STRIPING PLAN STA 24+00 - STA 30+45		
43	ROADWAY PLAN & PROFILE STA. 16+00 - 20+00	92	STRIPING DETAILS 1		
44	ROADWAY PLAN & PROFILE STA. 20+00 - 24+00	93	STRIPING DETAILS 2		
45	ROADWAY PLAN & PROFILE STA. 24+00 - 28+00	94	CONDUIT PLAN STA. 0+00-8+00		
46	ROADWAY PLAN & PROFILE STA. 28+00 - 31+05	95	CONDUIT PLAN STA. 8+00-16+00		
47	ROADWAY PLAN & PROFILE- WEST GATE BLVD AT DAVIS LANE TRANSITION	96	CONDUIT PLAN STA. 16+00-24+00		
48	ROADWAY CROSS SECTIONS STA. 0+00 - STA 2+50	97	CONDUIT PLAN STA. 24+00-30+69.70		
49	ROADWAY CROSS SECTIONS STA. 3+00 - STA. 5+50	98	CONDUIT STANDARD NOTES AND DETAILS SHEET 1		

APPROVED
JUN 0 8 2009
CITY OF AUSTIN WPDR DEVELOPMENT SERVICES

APPROVED
JAN 0 6 2010
CITY OF AUSTIN WPDR DEVELOPMENT SERVICES

NOV 1 9 2009

REVIEWED BY:

FOR WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT — DATE

SP-2008-0534D /
SITE PLAN/DEVELOPMENT PERMIT NUMBER

REV. NO.	BY	DATE	REVISION DESCRIPTION

STATE OF TEXAS — ADEWALE K. ODUFUYE — 91302 — LICENSED PROFESSIONAL ENGINEER

10/20/09

THE SEAL APPEARING ON THIS DOCUMENT WAS AUTHORIZED BY ADEWALE K. ODUFUYE, P.E., LIC# 91302

CITY OF AUSTIN, TEXAS
DEPARTMENT OF PUBLIC WORKS
ENGINEERING SERVICES DIVISION

WEST GATE BOULEVARD EXTENSION
CAMERON LOOP TO COHOBA DRIVE

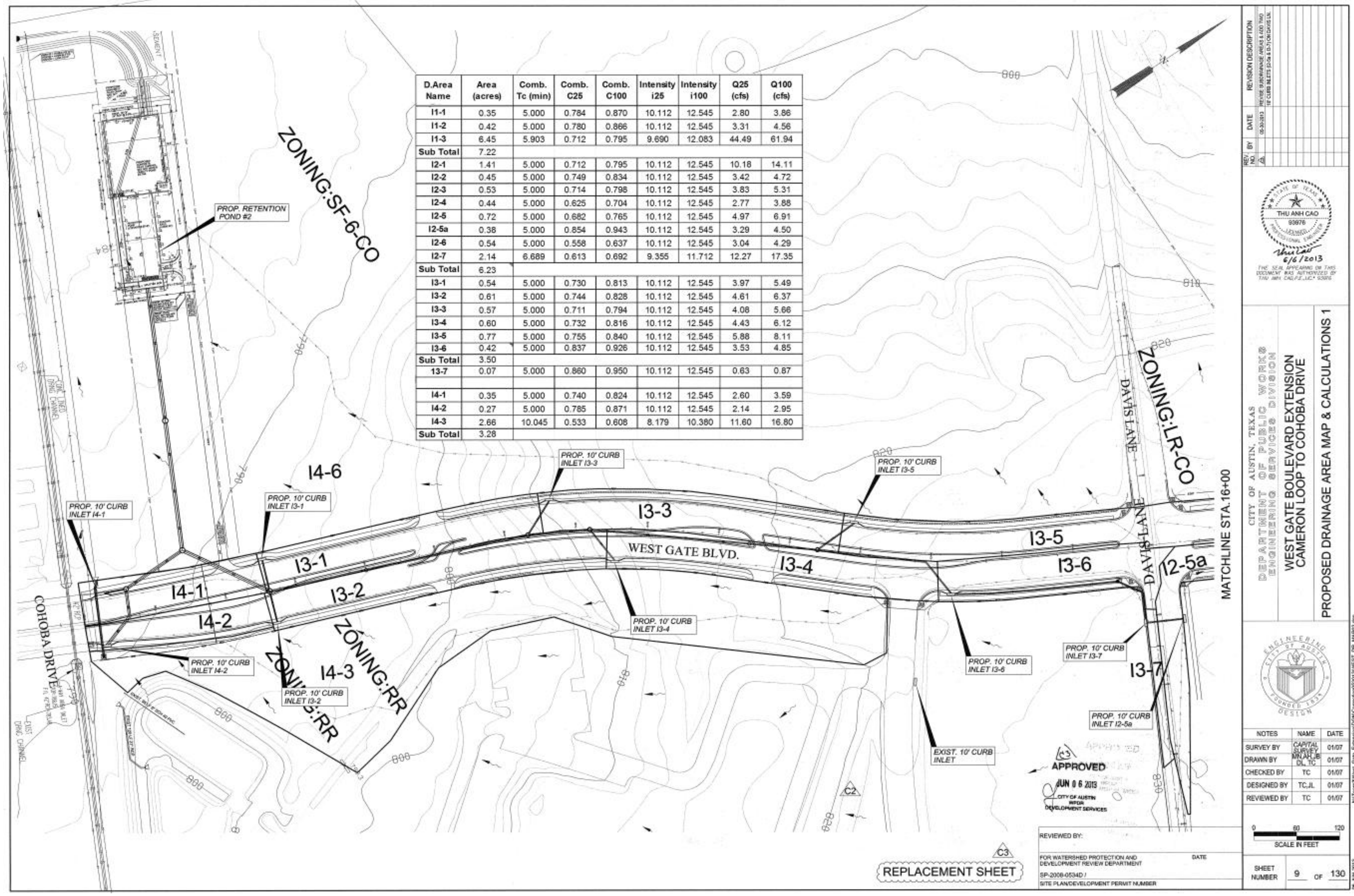
INDEX OF SHEETS

NOTES	NAME	DATE
SURVEY BY	CAPITAL SURVEY	01/07
DRAWN BY	MN,AH,JB DL, TC	01/07
CHECKED BY	TC	01/07
DESIGNED BY	MN, TC	01/07
REVIEWED BY	CT	01/07

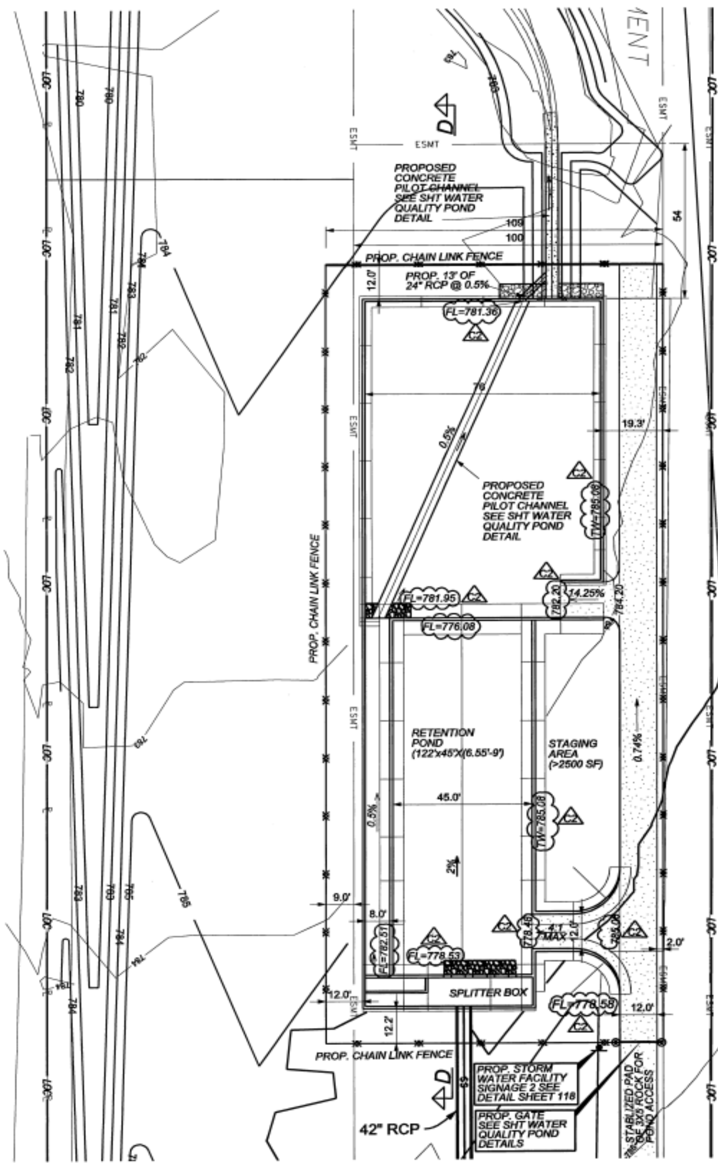
N.T.S.

SHEET NUMBER 2 OF 138

SP-2008-0534D



D.Area Name	Area (acres)	Comb. Tc (min)	Comb. C25	Comb. C100	Intensity i25	Intensity i100	Q25 (cfs)	Q100 (cfs)
I1-1	0.35	5.000	0.784	0.870	10.112	12.545	2.80	3.86
I1-2	0.42	5.000	0.780	0.866	10.112	12.545	3.31	4.56
I1-3	6.45	5.903	0.712	0.795	9.690	12.083	44.49	61.94
Sub Total	7.22							
I2-1	1.41	5.000	0.712	0.795	10.112	12.545	10.18	14.11
I2-2	0.45	5.000	0.749	0.834	10.112	12.545	3.42	4.72
I2-3	0.53	5.000	0.714	0.798	10.112	12.545	3.83	5.31
I2-4	0.44	5.000	0.625	0.704	10.112	12.545	2.77	3.88
I2-5	0.72	5.000	0.682	0.765	10.112	12.545	4.97	6.91
I2-5a	0.38	5.000	0.854	0.943	10.112	12.545	3.29	4.50
I2-6	0.54	5.000	0.558	0.637	10.112	12.545	3.04	4.29
I2-7	2.14	6.689	0.613	0.692	9.355	11.712	12.27	17.35
Sub Total	6.23							
I3-1	0.54	5.000	0.730	0.813	10.112	12.545	3.97	5.49
I3-2	0.61	5.000	0.744	0.828	10.112	12.545	4.61	6.37
I3-3	0.57	5.000	0.711	0.794	10.112	12.545	4.08	5.66
I3-4	0.60	5.000	0.732	0.816	10.112	12.545	4.43	6.12
I3-5	0.77	5.000	0.755	0.840	10.112	12.545	5.88	8.11
I3-6	0.42	5.000	0.837	0.926	10.112	12.545	3.53	4.85
Sub Total	3.50							
I3-7	0.07	5.000	0.860	0.950	10.112	12.545	0.63	0.87
I4-1	0.35	5.000	0.740	0.824	10.112	12.545	2.60	3.59
I4-2	0.27	5.000	0.785	0.871	10.112	12.545	2.14	2.95
I4-3	2.66	10.045	0.533	0.608	8.179	10.380	11.60	16.80
Sub Total	3.28							



DRAINAGE AREA DATA	S		
Design Peak Flow Rate (Q25)	cfs.		28.39
Design Peak Flow Rate (Q100)	cfs.		47.61
Drainage Area use for WQPond	ac.		3.87
Impervious Cover Percentage for WQ	%		70.07
Capture Depth (Table 1-12 ECM)	in.		1.86
WATER QUALITY CALCULATIONS			
	Provided	Unit	Required
Retention Volume (Vwqp=CD*area)		cf.	26,129.47
Sedimentation Pond Area (WQV/10)	5490.00	sf.	2612.95
Sedimentation Pond Volume (>=WQV)	28,685.25	cf.	26129.47
SPLITTER BOX			
Freeboard at Sed.Pond from HGL100 to T.O.Pond		ft.	1.00
FL of Split Box		ft. msl	778.58
Length of Splitter Weir		ft.	25.00
Top Surface of Sedimentation Pond		sf.	5490.00
Floor Surface of Sedimentation Pond		sf.	5490.00
Height of Splitter Weir or Water level of Sed. Pond		ft.	4.76
Water Quality Elevation		ft. msl	783.34
Elevation of Splitter Overflow Weir (>=WQ elev.)		ft. msl	783.34
Required Head to Pass Q25 at Splitter's Weir		ft.	0.52
Required Head to Pass Q100 at Splitter's Weir		ft.	0.74
Hydraulic Gradeline (Q25)		ft. msl	783.86
Hydraulic Gradeline (Q100)		ft. msl	784.08
Top of Split Box		ft. msl	784.08
Top of Berm		ft. msl	785.08

RETENTION POND			
Elevation	Area(sf.)	Volume(cf.)	Storage(cf.)
783.00			
781.45			
780.45	5490	5490	28,685.25
779.45	5490	5490	23,195.25
778.45	5490	5490	17,705.25
777.45	5490	5490	12,215.25
776.45	5490	6725	6,725.25
774	0		

IRRIGATION		
Existing Area for Irrigation	sf.	98297.94
Existing Area for Irrigation	ac.	2.26
Existing Soil Permeability	in/hr	
Required Soil Permeability	in/hr	

SITE RUN OFF

Sub Basin	Site Conditions	Area (ac)	Tc (min)	Hydrolic Soil Group	CN	Anticedent moisture	Storm Duration	Peak Run off (cfs) Q2	Q10	Q25	Q100
D2a	Existing	3.87	40.04	D	88	III	COA 24 hr.	8.804	17.5354	22.8511	30.7497
I3+I4-1+I4-2	Proposed	3.87	7.80	D	94	III	COA 24 hr.	10.9054	19.6372	24.9918	33.0068
I3+I4-1+I4-2	Proposed w/ Detention	3.87	7.80	D	94	III	COA 24 hr.	7.9025	15.5212	20.721	26.9567

DETENTION POND - STAGE/STORAGE/DISCHARGE

ORIFICE 1		WEIR 1		WEIR 2	
Crest(ft)=	781.36	Crest(ft)=	782.08	Crest(ft)=	783.08
Cd =	0.6	C=	0.62	C=	0.62
Dia (ft) =	2	L (ft)=	7	L (ft)=	9

Stage (FT)	Elevation (FT)	Contour Area (SF)	Contour Area (Acre)	Incremental Storage (ac-ft)	Volume Sum (ac-ft)	Orifice Head (ft)	Orifice Discharge (cfs) Q=Cd*A*(2gh)^0.5	Weir Head (ft)	Weir Discharge (cfs) Q=C*(L-0.2H)*(H^1.5)	Weir Head (ft)	Weir Discharge (cfs) Q=C*(L-0.2H)*(H^1.5)	Total discharge (cfs)
0	781.36	0	0	0	0	0.0	0	0	0	0	0	0
0.5	781.86	8284	0.1902	0.03	0.03	0.0	0.00	0	0.00	0	0.00	0.00
1	782.36	8284	0.1902	0.10	0.13	0.0	0.00	0.28	0.64	0	0.00	0.64
1.5	782.86	8284	0.1902	0.10	0.22	0.5	10.70	0.78	2.92	0.00	0.00	13.62
2.5	783.86	8284	0.1902	0.19	0.41	1.5	18.53	1.78	9.78	0.78	0.79	29.10
3.42	784.78	8284	0.1902	0.17	0.59	2.4	23.53	2.70	17.77	1.70	2.28	43.58

APPROVED KA SEP 1 9 2010

REVIEWED BY:

FOR WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT | DATE

SP-2008-0534D /
SITE PLAN/DEVELOPMENT PERMIT NUMBER

REV. NO.	BY	DATE	REVISION DESCRIPTION
1		~~9-00-2009~~	~~ADDENDUM #2~~
2		08-16-2010	REVISED ELEVATIONS, UPDATED POND CALCULATIONS, AND GRADING PLAN

STATE OF TEXAS
THU ANH CAO
93976
LICENSED PROFESSIONAL ENGINEER
9/15/2010

THE SEAL APPEARING ON THIS DOCUMENT WAS AUTHORIZED BY THU ANH CAO, P.E., LIC# 93976

CITY OF AUSTIN, TEXAS
DEPARTMENT OF PUBLIC WORKS
ENGINEERING SERVICES DIVISION

WEST GATE BOULEVARD EXTENSION
CAMERON LOOP TO COHOBA DRIVE

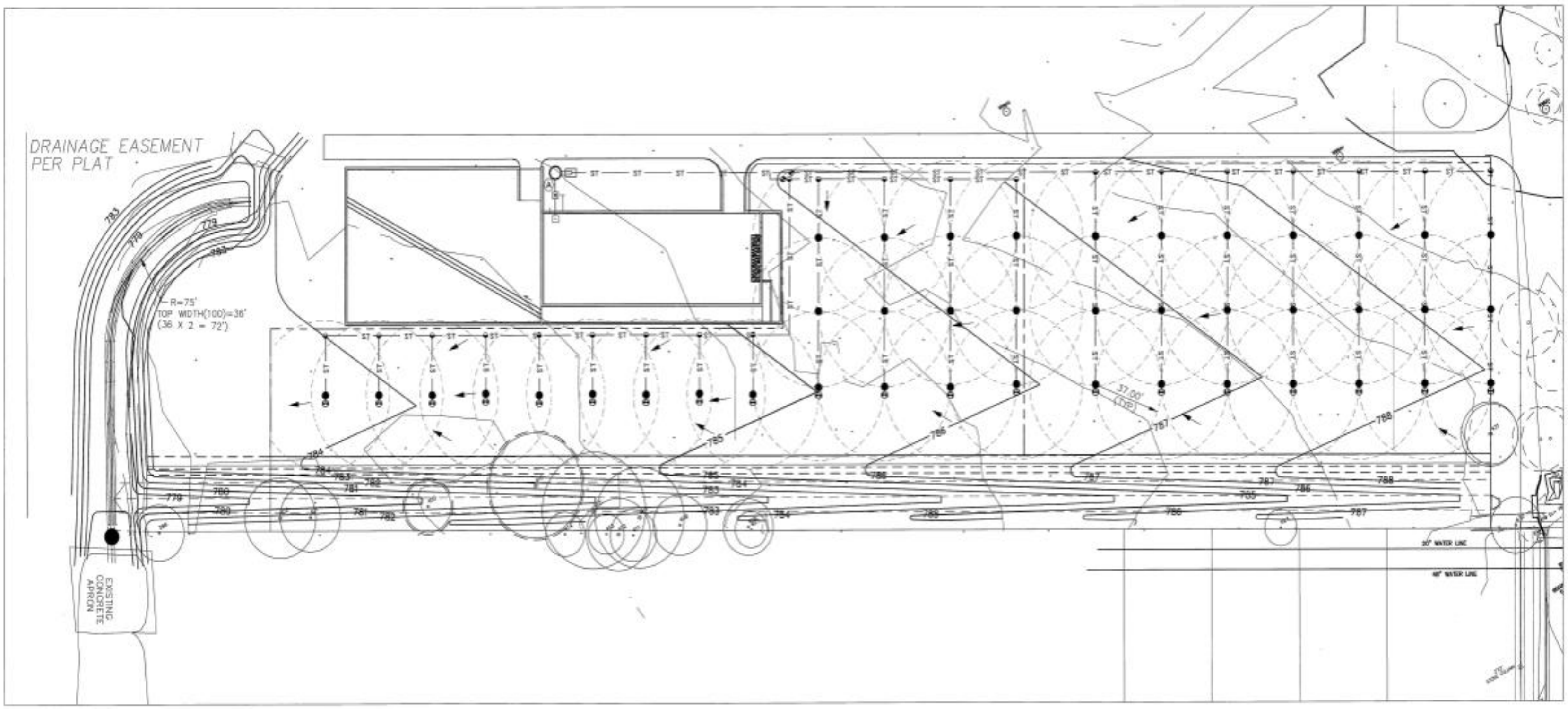
DRAINAGE - RETENTION & DETENTION POND 2 CALCULATION

ENGINEERING CITY OF AUSTIN DESIGN FOUNDED 1839

NOTES	NAME	DATE
SURVEY BY	CAPITAL SURVEY	01/07
DRAWN BY	MK,AH,JB,DL,TC	01/07
CHECKED BY	TC	01/07
DESIGNED BY	TC,JL	01/07
REVIEWED BY	CT	01/07

SCALE IN FEET 0 20 40

SHEET NUMBER 80 OF 142



APPROVED
JAN 06 2010

REV. NO.	BY	DATE	REVISION DESCRIPTION
1	WHH	6/25/09	BATCH SECTION REVISED
2	AHH	12/29/09	CLOUD REMOVED FROM PREVIOUS BID.

GARY L. STEGEMAN
LICENSED PROFESSIONAL ENGINEER
STATE OF TEXAS

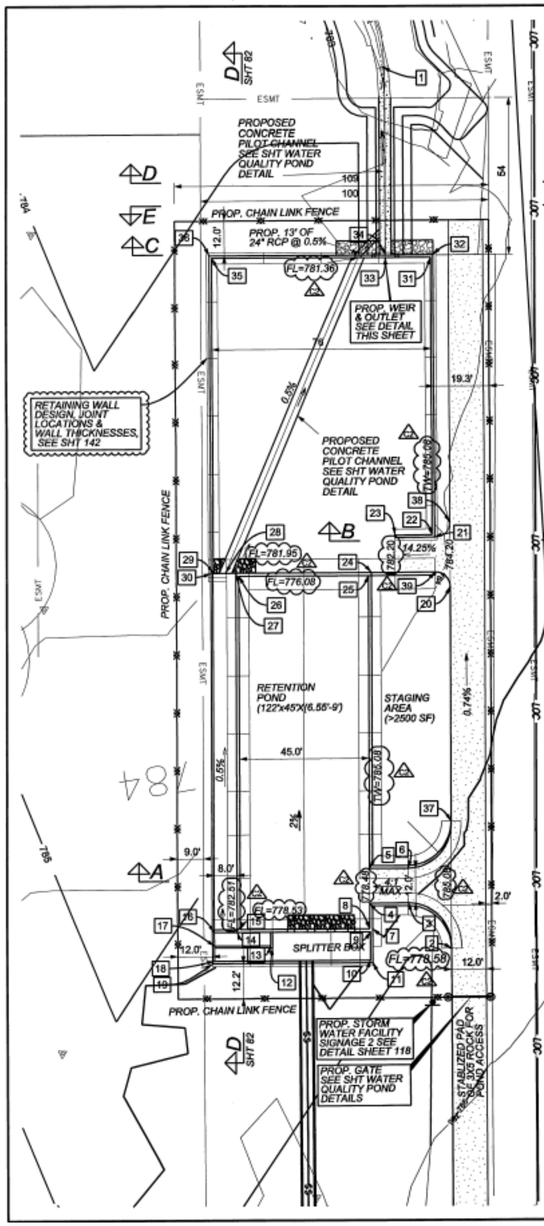
CAS CONSULTING & SERVICES INC
6633 HWY 290 EAST, SUITE 104
AUSTIN, TEXAS 78723
REG. No. F-003572

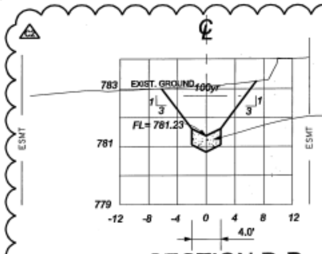
WEST GATE BOULEVARD EXTENSION CAMERON LOOP TO COHOBA DRIVE

SPRINKLER PATTERN

CITY OF AUSTIN ENGINEERING DESIGN

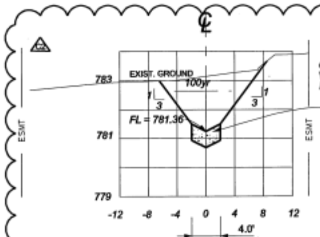
NOTES	NAME	DATE
SURVEY BY		06/09
DRAWN BY	EV	06/09
CHECKED BY	DN	06/09
DESIGNED BY	WC	06/09





SECTION D-D

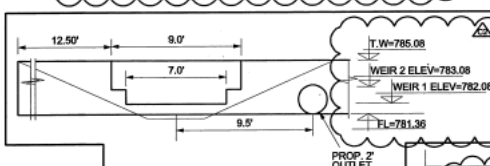
SCALE: 1"= 20' HORIZ.
1"= 2' VERT.



SECTION C-C

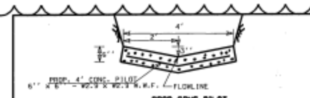
SCALE: 1"= 20' HORIZ.
1"= 2' VERT.

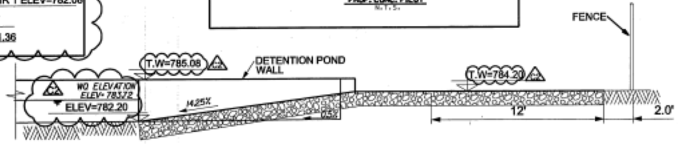
LOCATION	NORTHING	EASTING	ELEV.	DESCRIPTION
1	3084978.00	10041288.16	780.90	Flowline of existing pilot channel
2	3085258.90	10041168.13	785.33	Elevation of access road to Ret. Pond
3	3085237.80	10041162.18	785.00	Elevation of access road to Ret. pond
4	3085231.66	10041150.34	778.48	Elevation @ bottom of the Ret pond
5	3085221.00	10041155.71	778.48	Elevation @ bottom of the Ret pond
6	3085227.14	10041167.70	782.06	Elevation of access road to Ret. pond
7	3085240.11	10041147.09	785.08	Elevation @ top of the Splitter box
8	3085239.65	10041146.20	778.53	Elevation @ bottom of the Ret pond
9	3085240.62	10041145.88	778.58	Elevation @ bottom of the Splitter box
10	3085249.50	10041141.28	778.58	Elevation @ bottom of the Splitter box
11	3085250.62	10041141.64	785.08	Elevation @ top of the Splitter box
12	3085229.79	10041113.25	783.34	Elevation @ top of the Splitter box
13	3085228.84	10041112.95	778.58	Elevation @ bottom of the Splitter box
14	3085219.38	10041104.90	785.08	Elevation @ top of the Ret pond
15	3085218.95	10041106.24	778.53	Elevation @ bottom of the Ret pond
16	3085215.70	10041097.80	782.51	Elevation @ bottom of the Flume
17	3085219.87	10041095.63	778.58	Elevation @ bottom of the Splitter box
18	3085224.58	10041093.19	778.58	Elevation @ bottom of the Splitter box
19	3085225.01	10041092.22	785.08	Elevation @ top of the Splitter box
20	3085147.92	10041225.65	784.10	Elevation of access road to Det. Pond
21	3085130.37	10041228.74	785.08	Elevation @ top of the Det pond
22	3085129.25	10041228.38	782.28	Elevation @ bottom of the Det pond
23	3085123.32	10041216.95	785.08	Elevation @ top of the Det pond
24	3085130.90	10041203.68	785.08	Elevation @ top of the Ret pond
25	3085131.33	10041202.33	776.08	Elevation @ bottom of the Ret pond
26	3085110.63	10041162.38	776.08	Elevation @ bottom of the Ret pond
27	3085109.28	10041161.95	785.08	Elevation @ top of the Ret pond
28	3085110.59	10041158.69	781.95	Flowline of pilot channel
29	3085105.67	10041154.99	785.08	Elevation @ top of the Det pond
30	3085105.29	10041154.25	785.08	Elevation @ top of the Ret pond
31	3085043.72	10041272.70	781.36	Elevation @ bottom of the Det pond
32	3085043.36	10041273.83	785.08	Elevation @ top of the Det pond
33	3085036.51	10041258.80	782.08	Crest elevation of Weir 1
34	3085035.77	10041259.19	783.08	Crest elevation of Weir 2
35	3085008.75	10041205.75	781.36	Elevation @ bottom of the Det pond
36	3085007.62	10041204.87	785.08	Elevation @ top of the Det pond
37	3085219.84	10041188.38	784.84	Elevation of access road to Ret. Pond
38	3085128.38	10041235.77	784.05	Elevation of access road to Det. Pond
39	3085141.10	10041223.36	785.08	Elevation @ top of the Det pond



WEIR & OUTLET DETAIL

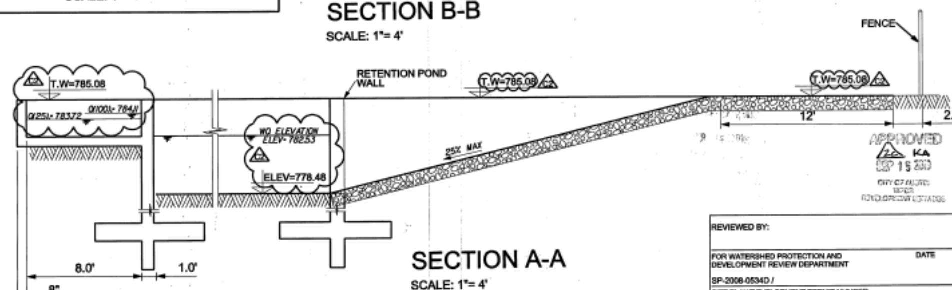
SECTION E-E
SCALE: 1"= 4'





SECTION B-B

SCALE: 1"= 4'



SECTION A-A

SCALE: 1"= 4'

REVIEWED BY:

FOR WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT | DATE

SP-2008-0534D / SITE PLAN/DEVELOPMENT PERMIT NUMBER

REV. NO.	BY	DATE	REVISION DESCRIPTION

THU ANH CAO 93976 LICENSED PROFESSIONAL ENGINEER

9/15/2010

THE SEAL APPEARING ON THIS DOCUMENT WAS AUTHORIZED BY THU ANH CAO, P.E., LIC# 93976

CITY OF AUSTIN, TEXAS
DEPARTMENT OF PUBLIC WORKS
ENGINEERING SERVICES DIVISION

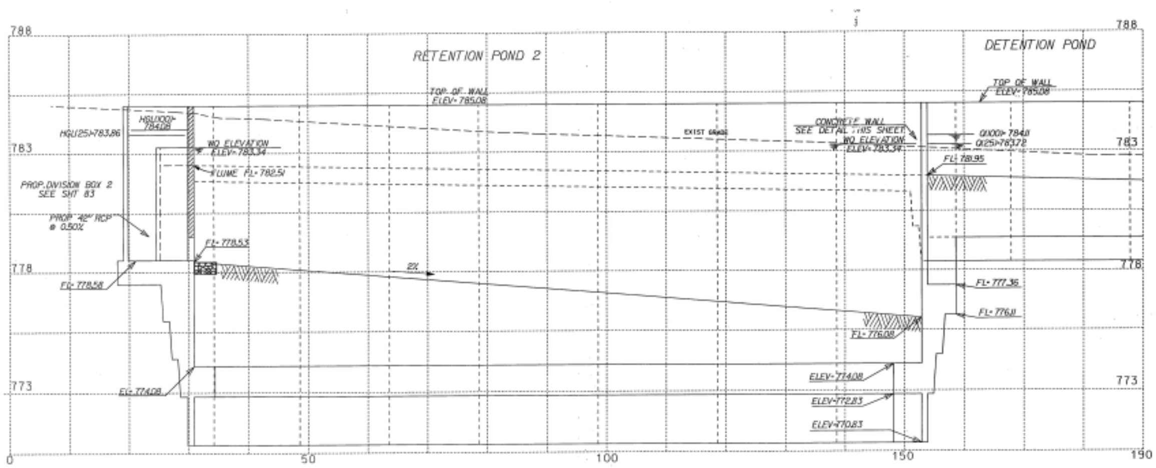
WEST GATE BOULEVARD EXTENSION
CAMERON LOOP TO COHOBA DRIVE

DRAINAGE - RETENTION & DETENTION POND 2 DETAILS

NOTES	NAME	DATE
SURVEY BY	CAPITAL SURVEY	01/07
DRAWN BY		01/07
CHECKED BY	TC	01/07
DESIGNED BY	TC,JL	01/07
REVIEWED BY	CT	01/07

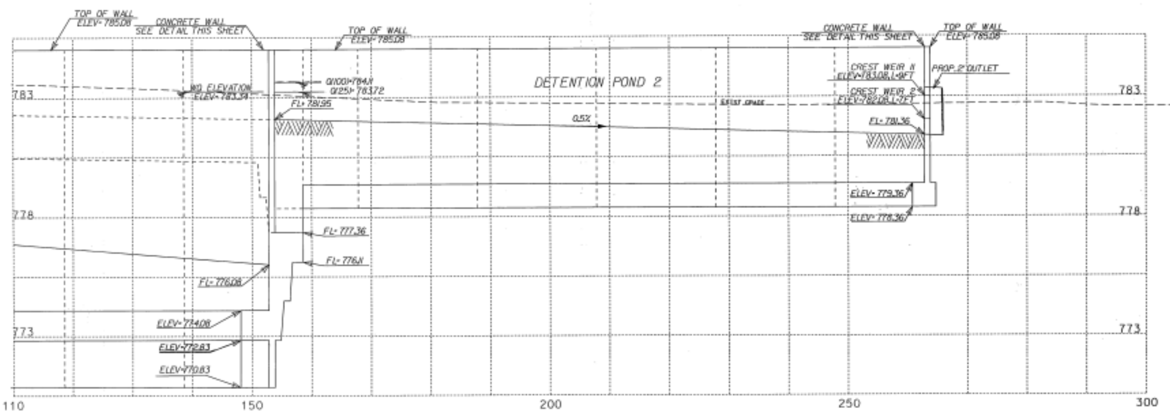
0 20 40 SCALE IN FEET

SHEET NUMBER 81 OF 142



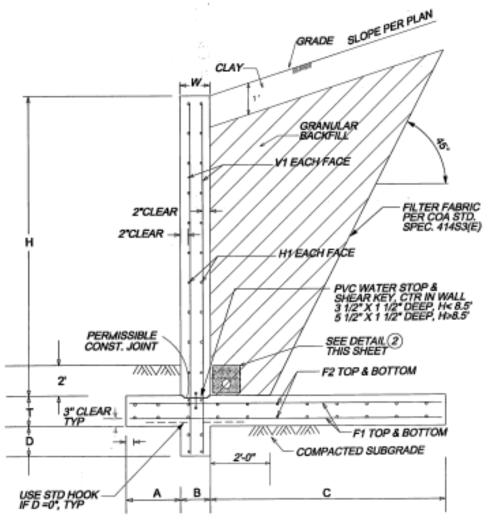
SECTION D-D (POND 2)

SCALE
1"=10' (HORIZ.)
1"=2.5' (VERT.)



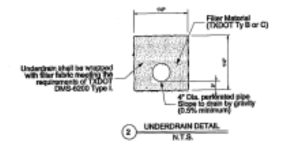
SECTION D-D (continued)

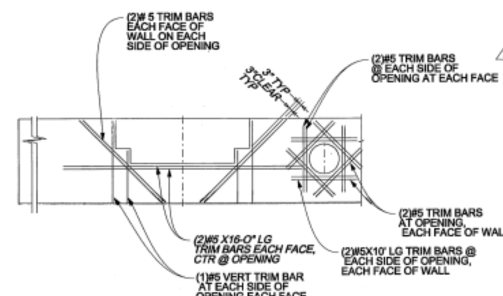
SCALE
1"=10' (HORIZ.)
1"=2.5' (VERT.)



RETAINING WALL DETAIL

NOT TO SCALE





APPROVED
KA
SEP 15 2010
CITY OF AUSTIN
DEVELOPMENT SERVICES

WEIR REINF. DETAIL

SEE SECTION E-E, SHT 81
FOR OPENING LOCATION
SCALE: 1"= 4'

C2

REPLACEMENT SHEET

MATERIALS PROPERTIES

1) CONCRETE= 4000 PSI CLASS S
2) REINF.= ASTM A615 GRADE 60
GEOTECH PARAMETERS USED IN DESIGN
(BASED ON COULOMB EARTH PRESSURE THEORY)
1) EFP (ACTIVE) =45 PCF
2) EFP (PASSIVE) =300 PCF(NEGLECT TOP 2')
3) ALLOWABLE SOIL BEARING = 3000 PSF
4) NO SURCHARGE
5) COEFFICENT OF FRICTION = 0.40

STATE OF TEXAS
CHRISTOPHER M. BRADBURY
104366
LICENSED PROFESSIONAL ENGINEER
9/15/10
THE SEAL APPEARING ON THIS DOCUMENT WAS AUTHORIZED BY CHRISTOPHER M.BRADBURY LIC# 104366 FOR RETAINING WALL ONLY

RETAINING WALL SCHEDULE

WALL DIMENSIONS							STEEL REINFORCEMENT				SAFETY FACTORS		
H	T	D	A	B	C	W	V1	H1	F1	F2	OVER-TURNING MOMENT	SLIDING	BEARING PRESSURE (PSF)
6'	1'-0"	0	2'-0"	10"	11"	10"	#5 @12"	#4@12"	#4@12"	#4@12"	2.38	1.2	1272
12'	1'-3"	2'-0"	3'-6"	1'-0"	3'-3"	1'-0"	#7@9"	#5@12"	#5@9"	#5@12"	2.56	1.2	1984

REVIEWED BY:

FOR WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT | DATE

SP-2008-0534D /
SITE PLAN/DEVELOPMENT PERMIT NUMBER

REV NO.	BY	DATE	REVISION DESCRIPTION
1		9-03-2009	ADDENDUM #2
2		12-23-09	CLOUD REMOVED FROM PREVIOUS BID
3		8-17-2010	REVISED RETAINING WALL STRUCTURE & ADDED WEIR DETAIL

STATE OF TEXAS
THU ANH CAO
93976
LICENSED PROFESSIONAL ENGINEER
9/15/2010
THE SEAL APPEARING ON THIS DOCUMENT WAS AUTHORIZED BY THU ANH CAO,P.E.,LIC# 93976

CITY OF AUSTIN, TEXAS
DEPARTMENT OF PUBLIC WORKS
ENGINEERING SERVICES DIVISION

WEST GATE BOULEVARD EXTENSION CAMERON LOOP TO COHOBA DRIVE

POND 2 CROSS SECTIONS

ENGINEERING CITY OF AUSTIN FOUNDED 1839 DESIGN

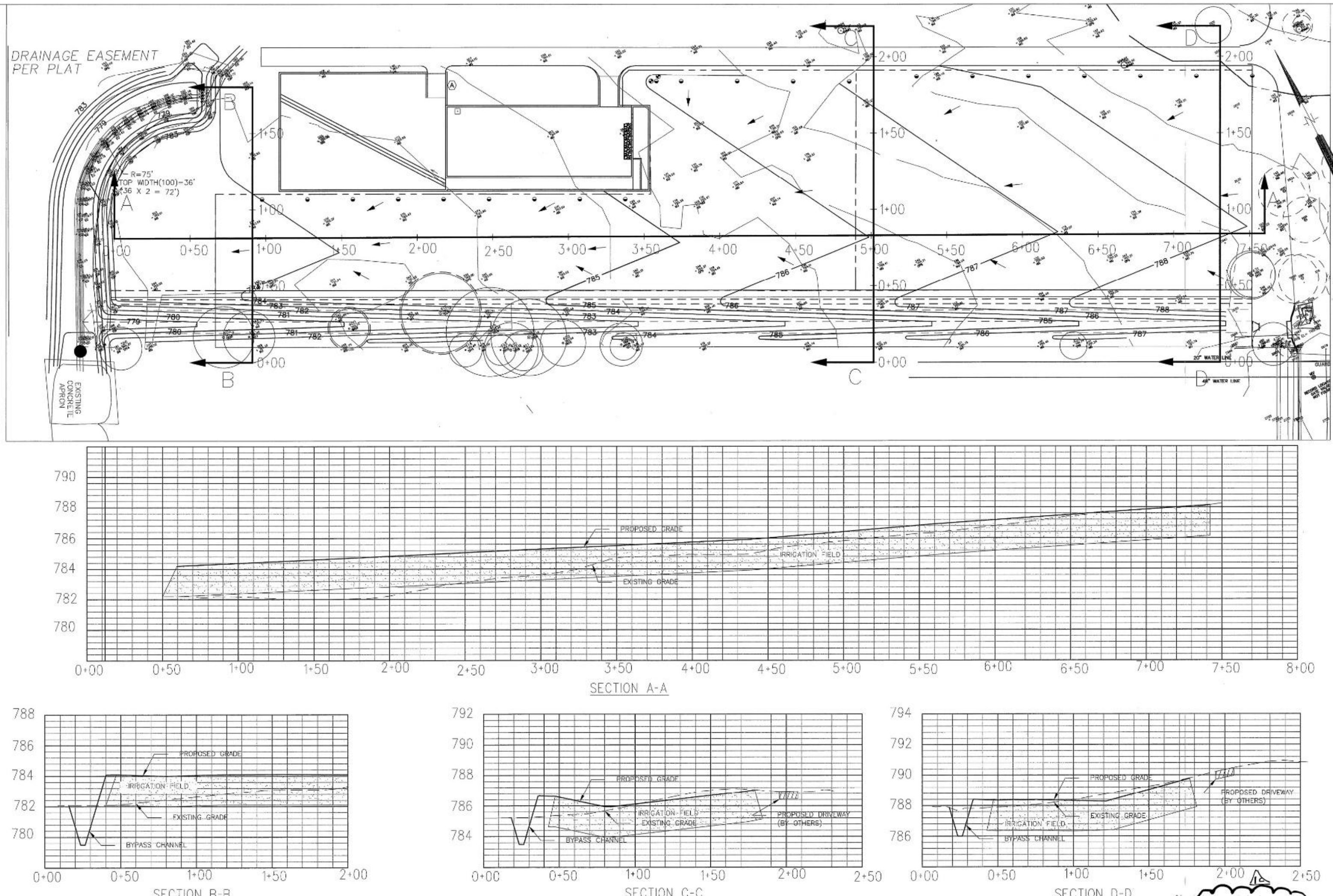
NOTES	NAME	DATE
SURVEY BY	CAPITAL SURVEY	01/07
DRAWN BY	MN,AR,JB DL,TC	01/07
CHECKED BY	TC	01/07
DESIGNED BY	TC,JL	01/07
REVIEWED BY	CT	01/07

HORIZONTAL SCALE IN FEET: 0 10 20
VERTICAL SCALE IN FEET: 0 2.5 5

SHEET NUMBER 82 OF 142

N:\Team5\West_Gate_Extension\DGN\Corrections\082510\WEST_DR_POND2.dgn

15-SEP-2010



REV. NO.	BY	DATE	REVISION DESCRIPTION
1		8/25/09	DITCH SECTION REVISED
2	AJW	2/29/09	CLOUD REMOVED FROM PREVIOUS BID.

GARY L. STEGMAN 90596 LICENSED PROFESSIONAL ENGINEER — STATE OF TEXAS

CAS CONSULTING & SERVICES INC
6633 HWY 290 EAST, SUITE 104
AUSTIN, TEXAS 78723
REG. No. F-003372

WEST GATE BOULEVARD EXTENSION CAMERON LOOP TO COHOBA DRIVE

GRADING PLAN

NOTES	NAME	DATE
SURVEY BY		06/09
DRAWN BY	EV	06/09
CHECKED BY	DN	06/09
DESIGNED BY	WC	06/09
REVIEWED BY	DN	06/09

SCALE IN FEET 0 30 60

SHEET NUMBER 84 OF 138

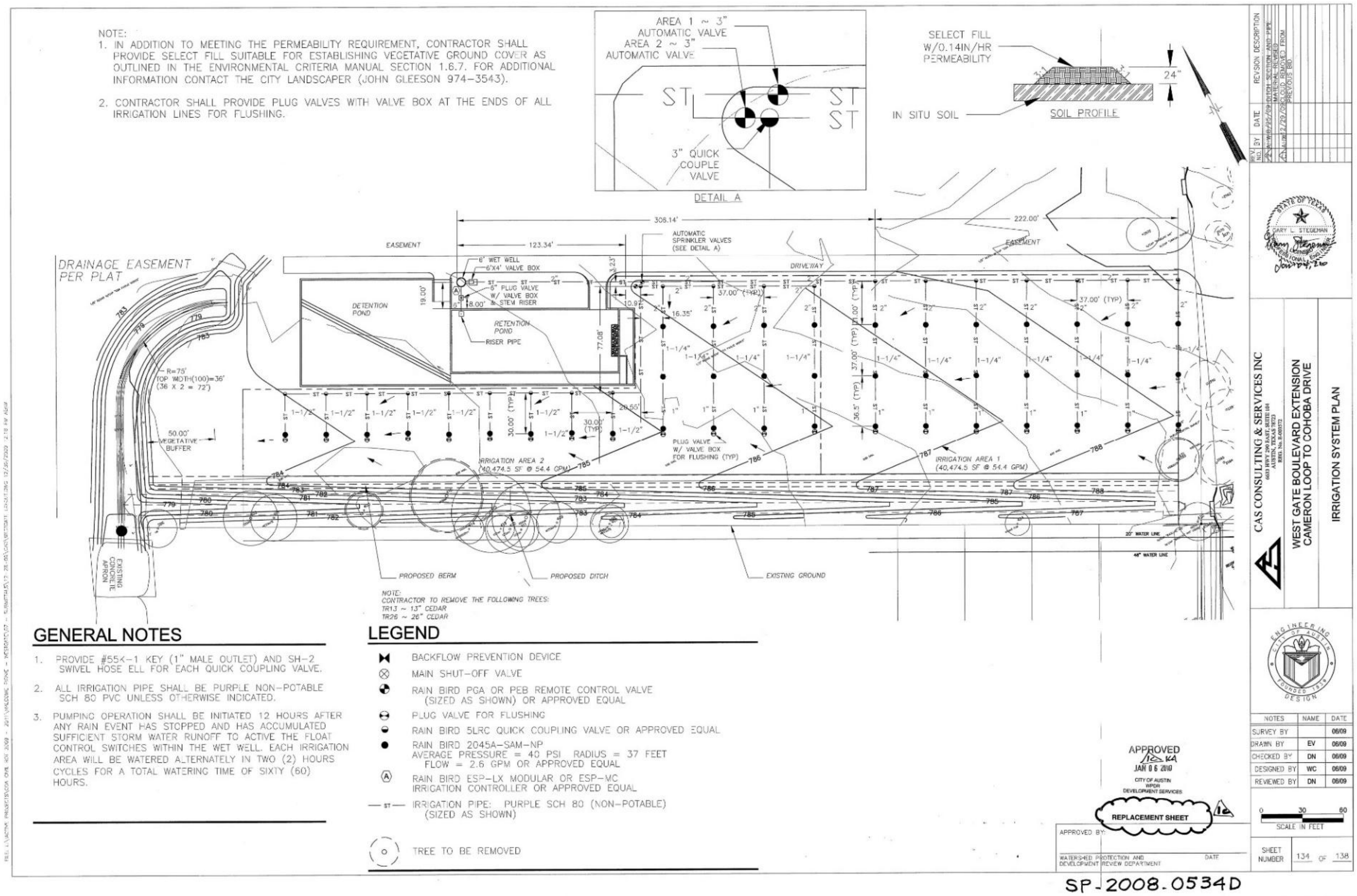
REPLACEMENT SHEET

APPROVED BY:

WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT DATE

APPROVED JAN 06 2010 CITY OF AUSTIN WPDR DEVELOPMENT SERVICES

SP-2008-0534D


NOTE:
1. IN ADDITION TO MEETING THE PERMEABILITY REQUIREMENT, CONTRACTOR SHALL PROVIDE SELECT FILL SUITABLE FOR ESTABLISHING VEGETATIVE GROUND COVER AS OUTLINED IN THE ENVIRONMENTAL CRITERIA MANUAL SECTION 1.6.7. FOR ADDITIONAL INFORMATION CONTACT THE CITY LANDSCAPER (JOHN GLEESON 974-3543).
2. CONTRACTOR SHALL PROVIDE PLUG VALVES WITH VALVE BOX AT THE ENDS OF ALL IRRIGATION LINES FOR FLUSHING.
AREA 1 ~ 3" AUTOMATIC VALVE
AREA 2 ~ 3" AUTOMATIC VALVE
3" QUICK COUPLE VALVE
DETAIL A
SELECT FILL W/0.14IN/HR PERMEABILITY
IN SITU SOIL
SOIL PROFILE
24"
DRAINAGE EASEMENT PER PLAT
EASEMENT
DETENTION POND
RETENTION POND
RISER PIPE
6" WET WELL
6'X4' VALVE BOX
AUTOMATIC SPRINKLER VALVES (SEE DETAIL A)
DRIVEWAY
PLUG VALVE W/ VALVE BOX FOR FLUSHING (TYP)
IRRIGATION AREA 2 (40,474.5 SF @ 54.4 GPM)
IRRIGATION AREA 1 (40,474.5 SF @ 54.4 GPM)
50.00' VEGETATIVE BUFFER
EXISTING CONCRETE APRON
PROPOSED BERM
PROPOSED DITCH
EXISTING GROUND
NOTE: CONTRACTOR TO REMOVE THE FOLLOWING TREES: TR13 ~ 13" CEDAR TR26 ~ 26" CEDAR
GENERAL NOTES
1. PROVIDE #55K-1 KEY (1" MALE OUTLET) AND SH-2 SWIVEL HOSE ELL FOR EACH QUICK COUPLING VALVE.
2. ALL IRRIGATION PIPE SHALL BE PURPLE NON-POTABLE SCH 80 PVC UNLESS OTHERWISE INDICATED.
3. PUMPING OPERATION SHALL BE INITIATED 12 HOURS AFTER ANY RAIN EVENT HAS STOPPED AND HAS ACCUMULATED SUFFICIENT STORM WATER RUNOFF TO ACTIVE THE FLOAT CONTROL SWITCHES WITHIN THE WET WELL. EACH IRRIGATION AREA WILL BE WATERED ALTERNATELY IN TWO (2) HOURS CYCLES FOR A TOTAL WATERING TIME OF SIXTY (60) HOURS.
LEGEND
BACKFLOW PREVENTION DEVICE
MAIN SHUT-OFF VALVE
RAIN BIRD PGA OR PEB REMOTE CONTROL VALVE (SIZED AS SHOWN) OR APPROVED EQUAL
PLUG VALVE FOR FLUSHING
RAIN BIRD 5LRC QUICK COUPLING VALVE OR APPROVED EQUAL
RAIN BIRD 2045A-SAM-NP AVERAGE PRESSURE = 40 PSI RADIUS = 37 FEET FLOW = 2.6 GPM OR APPROVED EQUAL
RAIN BIRD ESP-LX MODULAR OR ESP-MC IRRIGATION CONTROLLER OR APPROVED EQUAL
IRRIGATION PIPE: PURPLE SCH 80 (NON-POTABLE) (SIZED AS SHOWN)
TREE TO BE REMOVED
CAS CONSULTING & SERVICES INC
WEST GATE BOULEVARD EXTENSION CAMERON LOOP TO COHOBA DRIVE
IRRIGATION SYSTEM PLAN
APPROVED JAN 0 6 2010 CITY OF AUSTIN DEVELOPMENT SERVICES
REPLACEMENT SHEET
APPROVED BY
WATERSHED PROTECTION AND DEVELOPMENT REVIEW DEPARTMENT
DATE
SURVEY BY 06/09
DRAWN BY EV 06/09
CHECKED BY DN 06/09
DESIGNED BY WC 06/09
REVIEWED BY DN 06/09
SCALE IN FEET
SHEET NUMBER 134 OF 138
SP-2008.0534D