SAN BERNARDINO Valley MUNICIPAL WATER DISTRICT

IN COOPERATION WITH:
SAN GORGONIO PASS WATER AGENCY
CITY OF CALIMESA
CITY OF YUCAIPA
CITY OF REDLANDS
SOUTH MESA WATER COMPANY
WESTERN HEIGHTS WATER COMPANY
YUCAIPA VALLEY WATER DISTRICT

FINAL
INFILTRATION TESTING AT ELEVEN INVESTIGATION SITES IN THE YUCAIPA BASIN

YUCAIPA, CALIFORNIA

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1. INTRODUCTION

The San Bernardino Valley Municipal Water District (Valley District) and its partner agencies are evaluating the feasibility of recharging State Water Project (SWP) water and recycled water and enhancing local stormwater capture in the Yucaipa Basin. Successful management of the Yucaipa Basin conjunctively with available surface water supplies will increase the basin safe yield to meet projected groundwater demands and help to achieve sustainability goals and management criteria to be established in the Yucaipa Basin Groundwater Sustainability Plan (GSP).

In March 2018, Valley District contracted Todd Groundwater to perform infiltration tests at (up to) thirteen sites in the Yucaipa Basin. Infiltration testing represents an important step in evaluating site recharge capacity and feasibility. Short-term tests using field-scale test basins were selected to balance the need to test a reasonably-sized area at each investigation site, while considering the substantial number of sites and water delivery constraints of local fire hydrants used for test water. Combined with the current understanding of the basin hydrogeologic conditions, infiltration test results were used to satisfy the following project objectives:

- Confirm site infiltration capacity and recharge suitability. Favorable conditions are characterized by (1) predominantly coarse-grained (sand/gravel) vadose zone lithology that allow unhindered vertical migration of recharge water to the water table; (2) sufficient depth to water and horizontal distance from vertical hydraulic barriers (e.g., faults) to accommodate future recharge mounding; and (3) an upgradient location relative to groundwater production areas/pumping depressions

- Develop planning-level estimates of long-term infiltration rates to support future evaluation and design of recharge facilities to optimize groundwater water level, storage, and safe yield and water quality benefits in the Yucaipa Basin

- Recommend additional field investigations (e.g., monitoring well construction and pilot scale testing) to address remaining knowledge gaps at high-priority investigation sites

Guidelines for implementation of infiltration testing were developed in a Work Plan developed by Todd Groundwater (Todd, 2017). Due to the inability to gain access to one privately-owned site (Garden Air Creek) and the de-prioritization of a second site due to its downgradient location in the Yucaipa Basin (Wildwood Creek at 6th Street), infiltration testing was conducted at only eleven of the original thirteen investigation sites included in the Work Plan. Two infiltration tests were conducted at the Oak Glen Creek Basins to assess the significance of surficial low-permeability sediments on infiltration rates. Accordingly, a total of twelve infiltration tests were completed.

This report describes the infiltration test methods, activities, and results. Calculated infiltration rates are presented along with preliminary estimates of long-term infiltration rates for a full-scale recharge basin to support the Yucaipa Basin GSP process. Knowledge gaps and recommendations for additional investigation work at favorable recharge sites are also presented to support the design of new recharge facilities and rehabilitation of existing recharge/storm detention basins.

1.1. Scope of Work

The scope of work for the investigation included the following activities:

1. Attendance at a pre-construction meeting (held on May 15, 2018) to confirm site access for heavy machinery; delineate test basin excavation limits and dimensions; confirm preferred water source, pressure, and anticipated delivery rates; and review procedures for test basin construction, soils management requirements, conveyance and instrument setup, and site security fencing and traffic control.

2. Refinement of detailed site-specific work plans to accommodate physical constraints prior to field mobilization, and determination of the optimal test sequence based on site prioritization and intra-site proximity to consolidate equipment requirements and minimize rental costs.

3. Fabrication of two flow control systems/skids and associated valves and switches for automated flow and water level control and alert functions.

4. Implementation of twelve infiltration tests at eleven sites (conducted over a twelve-week period from July 9 to October 1, 2018). Activities included (a) mobilization and demobilization of equipment and heavy machinery, (b) excavation and backfill of an approximately 1,000-square foot (ft^2) by 5-foot deep test basin, and (c) installation of test equipment, site monitoring components, security fencing, and traffic ramps and signage to ensure reliable collection of field data and public safety.

5. Routine site visits to document flow rates/volumes and non-routine site visits to troubleshoot/address equipment issues and modify the test approach to maximize the value of collected data.

6. Project Management. Todd Groundwater subcontracted Drewelow Remediation Equipment Inc. (DRE) (Escondido, California) to fabricate the flow control systems/skids and implement the field infiltration testing. Todd Groundwater provided overall project management, field supervision, and schedule coordination for the project.

1.2. Previous Investigations

Over the past several years, Valley District and its partner agencies have been proactive in building the technical foundation for developing a groundwater recharge program in the Yucaipa Basin. Recent studies and investigations have improved the understanding of local hydrogeologic conditions, including the geologic structure of the basin, vadose zone and aquifer characteristics, location and hydraulic effect of geologic faults, groundwater level trends, and groundwater quality distribution (Geoscience, 2014b; USGS, 2001 and 2016). Additionally, estimates of groundwater storage, usable storage, and safe yield (Geoscience, 2014a and 2015) have revealed the need to manage the groundwater basin conjunctively.

Yucaipa Valley Water District has been recharging in the Yucaipa Basin for the past decade. However, only two studies have directly tested the infiltration capacity of surficial sediments, findings from which are useful for interpreting infiltration test results for this investigation. In 1969, the USGS performed a 26-day pilot-scale infiltration test at the Wilson Creek Basins (Mooreland, 1970). The test involved creating a 100-feet square test pit by scraping the upper 1-foot of basin sediment into a 4-foot high berm. A total of 27 acre-feet of water over a wetted area ranging from 3,000 to 5,125 ft^2 was infiltrated. Ponded water levels in the test pit ranged up to 3 feet and averaged less than 1 foot. Results indicated an infiltration rate of approximately 16 feet/day (after initial adsorptive forces and air entrainment influences were removed), with a gradual decline to approximately 12 feet/day after 14 days, and 9 feet/day after 26 days. Declines were attributed to the development of a shallow perching condition about 30 feet below ground surface caused by apparent fine-grained sediments and observed in a shallow piezometer during testing.

From December 2017 through January 2018, the City of Yucaipa, Yucaipa Valley Water District (YVWD), Valley District, and San Bernardino County Flood Control District (SBCFCD) performed full-scale infiltration testing at the three basins (two detention basins to the west and easterly debris basin) comprising the Oak Glen Creek Basins (City of Yucaipa, et al., 2018). SWP water was used to pre-wet all three basins for eleven days prior to testing. Testing consisted of isolating each basin sequentially until a steady-state recharge rate was achieved in all three basins. Results revealed steady-state infiltration rates of 4.3 feet/day in the upper, eastern debris basin, 3.3 feet/day in the middle basin (the same basin tested for this investigation), and 1.8 feet/day in the lower, western basin. It is noted that the full-scale infiltration testing was conducted on the undisturbed basin bottoms (with no removal of historically accumulated fine-grained clogging materials).

In addition to local investigations, foundational research in clogging dynamics in surface spreading basins (Phipps, D.W., Lyon, S., and Hutchinson, A., 2007; see Appendix A) and discussions with Orange County Water District (OCWD) (Adam Hutchinson, Recharge Planning Manager, personal communication, November 7, 2018) were used to predict initial and long-term infiltration rates for full-scale recharge basins at each investigation site. Descriptions are provided in the site-specific results of the assumptions used to account for unknown variables, including the dimensions of a full-scale recharge facility, site recharge goals and active spreading period, and approach/frequency of basin maintenance.

2. INVESTIGATION SITES AND TEST METHODOLOGY

2.1. INVESTIGATION SITES

Figure 1 show the locations of the eleven investigation sites in the Yucaipa Basin for which infiltration testing was completed. Site information is summarized in **Table 1**, including the assessor's parcel number, test basin location relative to previously-established Yucaipa Subbasin boundaries (Geoscience 2014a), regulatory jurisdiction, geographic coordinates, water source, and site directions.

The eleven investigation sites include undeveloped parcels and storm detention basins/channel reaches along Oak Glen Creek, Wilson Creek, and Wildwood Creek. Sites are owned by the San Bernardino County Flood Control District (5 sites), City of Yucaipa (5 sites), and South Mountain Water Company (1 site). All sites are located within an approximately 3-mile radius of downtown Yucaipa, California.

Six investigation sites ("SBCFCD Permit Sites" in Table 1) are located within stream channels (Wilson Creek, Oak Glen Creek, and Wildwood Creek) or existing storm detention basin facilities under jurisdiction of SBCFCD. All six sites are located on parcels owned by SBCFCD except for the Wildwood Creek Basins, which are owned by the City of Yucaipa.

Of the five sites not under the jurisdiction of SBCFCD, four investigation sites are owned by the City of Yucaipa (Tennessee Street Basins, Chapman Heights Basins, Dunlap Channel, and a parcel south of Wildwood Creek near California Street adjacent to EX-5). One site is owned by the South Mountain Water Company (adjacent to exploratory borehole EX-7).

2.2. INFILTRATION TEST METHODOLOGY

Infiltration tests involved the temporary construction of an approximately 1,000-square-foot (ft^2) test infiltration basin, installation and connection of a flow control system (skid) to a local fire hydrant to automate filling and maintenance of a constant ponded water level, and monitoring of added water volumes over an approximate 2-week testing period.

Testing was conducted at two investigation sites at a time, with site setup and test initiation staggered one week apart. This process was repeated as needed to complete twelve infiltration tests at the eleven investigation sites. The field program design provided the following advantages: (1) the contractor was on a fixed weekly schedule for test basin excavation, equipment mobilization/demobilization and monitoring activities, and (2) materials and labor (including fire hose, manifolds, basin trees, and traffic ramps/signage) were required for exactly two sites for the duration of the project.

Table 1

Investigation Site Information

Investigation Site	Yucaipa Subbasin	Owner	APN	Longitude[1]	Latitude[1]	USGS 7.5' Quad	TRS and 1/4 Section (San Bernardino)	Site Topography	Water Source	Directions
SBCFCD Permit Sites										
Wilson Creek Basins (EX-1)	Gateway	SBCFCD	032-105-227	-117.030015	34.051027	Yucaipa	1S/1W-30N	Within Existing Basin	YVWD Hydrant	1000 feet north of Oak Glen Road, 1,400 feet west of Fremont Street, third basin (including debris basin) west of Fremont St
Oak Glen Creek Basins (EX-2)	Gateway/ Wilson Creek	SBCFCD	032-131-112	-117.032033	34.044858	Yucaipa	1S/1W-31D	Within Existing Basin	YVWD Hydrant	off Eucalyptus Ave, 800 feet east of Bryant Street; second (middle) basin from Bryant Street
Wilson Creek III (EX-3)	Gateway	SBCFCD	030-319-104	-117.043082	34.043637	Yucaipa	1S/2W-36F	New Temporary Basin	YVWD Hydrant	1,800 feet south of Oak Glen Road, 600 feet north of Persimmon Ave at low elevation point east shoulder of 2nd Street;
Wildwood Creek Basins (EX-4)	Oak Glen	City of Yucaipa	124-227-103	-117.019498	34.014135	Yucaipa	2S/1W-7H	Within Existing Basin	SMWC hydrant	500 feet south of Wildwood Canyon Road, 3,800 feet east of Bryant Street
Wildwood Creek at California St (EX-5)	Calimesa	SBCFCD	031-922-103	-117.038309	34.014324	Yucaipa	2S/2W-12H	Within Existing Channel	SMWC hydrant	500 feet downstream (west) of California Street overpass
Oak Glen Creek at Western Heights (EX-9)	Western Heights	SBCFCD	031-801-328	-117.081389	34.030639	Yucaipa	2S/2W-3C	Within Existing Channel	YVWD Hydrant	250 feet upstream (northeast) of Avenue D overpass
Non-SBCFCD Permit Sites										
Tennessee Street Basins	(northwest of) Western Heights	City of Yucaipa	029-940-118	-117.105355	34.034223	Yucaipa	1S/2W-32R	Within Existing Basin	YVWD Hydrant	150 feet north of Tennessee Street, 700 feet west of 16th Street
Chapman Heights Basins	(northwest of) Western Heights	City of Yucaipa	029-932-105	-117.091425	34.037633	Yucaipa	1S/2W-33K	New Temporary Basin	YVWD Hydrant	300 feet northeast or intersection between Chapman Heights Road and 13th Street
Dunlap Channel	Western Heights	City of Yucaipa	030-103-207	-117.096333	34.030576	Yucaipa	2S/2W-4C	Within Existing Channel	WHWC hydrant	100 feet north of 14th Street and 280 feet east of Avenue D
City of Yucaipa at California St (EX-5)	Calimesa	City of Yucaipa	031-922-105	-117.037877	34.013731	Yucaipa	2S/2W-12H	New Temporary Basin	SMWC hydrant	300 feet west of California Street and 200 feet south of Wildwood Creek
10th St and Avenue E (EX-7)	Calimesa	South Mountain Water Company	031-806-107	-117.079686	34.025108	Yucaipa	2S/2W-3L	New Temporary Basin	YVWD Hydrant	100 feet east of 10th street between Avenue E and Washington Drive

Notes:
SBCFCD - San Bernardino County Flood Control District
YVWD - Yucaipa Valley Water District
WHWC – Western Heights Water Company
SMWC – South Mesa Water Company
1 - North America Datum 1983

The construction of each test infiltration basin was accomplished using a backhoe loader and involved earthwork, temporary soils management, and backfilling and final grading. With the exception of one test, basins were excavated to 5 feet below ground surface (feet-bgs) with excavated material stockpiled next to the basin. Native material was used to create shallow berms for one test at the Oak Glen Creek Basins to test the infiltration through undisturbed sediment at the ground surface. Ponded water depths typically ranged from 2.5 and 3.0 feet.

Test basins were constructed with an approximate 1-to-1 horizontal-to-vertical slope on one sidewall for public safety. At the completion of infiltration testing, each test basin was backfilled with the excavated material, and the site was returned to its original, pre-disturbed grade.

General mobilization, testing, and demobilization tasks at each investigation site are summarized below:

- Excavation of a test recharge basin at each site;
- Movement and staging of vehicles and heavy equipment along access routes and in vicinity of infiltration test basin;
- Temporary storage of excavated soils adjacent to the test basin;
- Installation of construction fencing to ensure public safety and prevent vandalism of water hoses and flow control equipment;
- Placement of traffic-rated ramps (to protect fire hose crossing public roads, driveways, and/or sidewalks) and traffic-control signs to direct vehicular and pedestrian traffic;
- Discharge of water into the test basin up to 14 days;
- Backfilling the test basin with excavated material to return the site to pre-disturbed grade.

2.3. Water Source, Flow Control, and Telemetry System

Average vertical infiltration rates at each site ranged from less than 1 feet per day (feet/day) up to approximately 50 feet/day. This equated to test water needs ranging from less than 5 gallons per minute (gpm) up to 200 gpm. Higher infiltration rates occurred in basins underlain by a thick deposit of coarse-grained vadose zone sediments (e.g., within existing larger flood control facilities, Oak Glen Creek Basins, and Wildwood Creek). Lower infiltration rates occurred in test basins underlain by finer-grained sediments.

To accommodate the potentially broad range of test water needs, a direct connection to a local fire hydrant owned by either Yucaipa Valley Water District (YVWD), South Mesa Water company (SMWC), or Western Heights Water Company (WHWC) was used to supply test water for each infiltration test. The use of a hydrant precluded the need for onsite water storage and provided adequate positive pressure in the water conveyance system to maintain flows into the basin required to achieve constant-head conditions. Water retailers include YVWD, SMWC, and WHWC.

Additionally, a robust, automated engineered water conveyance and flow control system with remote terminal unit (telemetry system) was fabricated by DRE and installed at each test basin. The flow control system provided the following benefits:

1. The flow rate was typically automatically controlled, providing a high range of discharge rates to match variable infiltration rates during testing and from site-to-site. Due to very high infiltration capacities at two sites, the largest 3" manual valve was opened partially to ensure constant water levels were maintained.
2. The flow rate range was controlled by adjustment of the pressure regulator setting and hand valves to accommodate variable pressure from different water sources.
3. No water storage tank was needed.
4. The system was installed with built-in telemetry to provide real-time flow rates into the basin, ponded water level, and notifications of exceedances of low-water and high-water level thresholds.
5. The system precluded Valley District or DRE staff to manually monitor flow volume and pond height.
6. Redundancy of flow meters at the hydrant connection and on two 1-inch and one 3-inch discharge lines allowed for flow rates entering the test basin to be reliably tracked.
7. The flow control system was supported by the edge of the test basin with two supporting feet at the bottom of the basin. The small footprint did not influence the infiltrating area of the test basin.

The conveyance system includes a totalizing flow meter, backflow prevention device, and hand valves (supplied by the owner of each hydrant). Water was conveyed from the hydrant by a combination of 4-inch diameter fire hose to an engineered manifold made with rigid steel pipe. A 4-inch diameter flexible fire hose was needed to maintain water pressure over the distances (generally between several hundred feet up to 1,500 feet) and head differences between the hydrant and test basin. A digital paddle meter was installed on the 4" diameter line before a manifold that separated the flow into three individual discharge pipes (one 3-inch diameter pipe and two 1-inch diameter pipes). A hand valve on the 3" diameter discharge line, and float valves and totalizing flowmeters on each 1" diameter line allowed for flow into the test basin to be automatically controlled to maintain ponded water depths typically between 2.5 and 3.0 feet. The three individual flowmeters were used to verify flows from the single fire hydrant flowmeter.

The system would also be equipped with high and low water level sensors and telemetry to communicate if water levels fell below 1 feet or exceeded 4 feet. Additionally, a low-pressure sensor upstream of the pressure regulator on the 4-inch manifold provided an automated warning if pressure from the fire hose dropped below a certain threshold, indicating that the water source itself or the fire hose was compromised and not able to provide water to the test basin. The low-pressure alarm was never triggered during the field investigation.

2.4. Monitoring Activities

The telemetry built in to the engineered water conveyance and flow control system minimized the need for onsite monitoring. Nevertheless, documentation of water meter readings for each test basin and maintenance of the systems was needed, especially at three sites where flows into the test basin fell below the minimum threshold of the digital paddle meter (approximately 25 gpm). For these three tests, routine twice-weekly site visits by DRE staff were supplemented by additional site visits by Valley District staff to document water meter readings and calculate average vertical infiltration rates for time periods between meter readings.

It is likely that recharged water reached the water table at some investigation sites during or following infiltration testing. Groundwater level monitoring was conducted during testing at one site (Wildwood Creek Basins), where an existing piezometer (YRP-PZ3; constructed in EX-4) is located relatively close to the test basin, and the depth to water (104 feet-bgs in 2014) is shallow enough that a measurable groundwater level response was expected. Confirmation of such a water level response is useful for validating the vertical migration of recharge water and inferring the degree of horizontal spreading of recharged water below the test basin. Water level monitoring in existing piezometers at the Wilson Creek Basins and Oak Glen Creek Basins was not performed, due to the significant horizontal distance between the piezometer and test basin and relatively deep water table at both sites (272 and 302 feet-bgs in 2014, respectively).

2.5. Best Management Practices

All field activities were conducted to ensure minimal disturbance to native vegetation and minimize soil erosion along channel banks. The following site management practices were implemented to satisfy requirements specified by the SBCFCD:

- No sediments were discharged to the storm drain system or receiving waters.
- Sediments generated on the construction site were retained.
- No construction-related materials, waste, spills, or residue were discharged to streets, drainage facilities, receiving waters, or adjacent property by wind or runoff.
- Non-stormwater runoff from equipment, vehicle washing, or any other activity were contained within the project site.
- Erosion from slopes and channels were prevented.
- Grading was not conducted during the wet season (October 1st through May 31st). All erosion-susceptible slopes were protected to prevent sediment discharge from the project site. Straw wattles were used to contain temporary stockpiled soils.

3. INFILTRATION TEST RESULTS

Infiltration testing was conducted over an uninterrupted 12-week period from July 9 to October 1, 2018. A synopsis of each infiltration test is presented on **Figures 2 through 13** and depict calculated infiltration rates, cumulative water volume added, and pond water levels over time, along with selected field photographs. Key conclusions, remaining knowledge gaps, and recommendations for additional investigation work are included in the bottom right text box of each figure.

Table 2 summarizes the results of all twelve infiltration tests, including the test period, basin dimensions, infiltrating area, total volume of infiltrated water, and calculated one-dimensional vertical infiltration rates. Investigation sites are arranged in the order that tests were completed. Infiltration rates from the main constant-head tests were calculated based on data near the end of each test after flow rates had stabilized and become effectively asymptotic (discussions of infiltration rate trends are discussed further in respective site-specific discussions later in this section). As shown in the table, infiltration rates were calculated based on an infiltrating area equal to the basin bottom footprint only (high infiltration rate) as well as based on an infiltrating area equal to the basin bottom footprint and saturated sidewall area (low infiltration rate). An average rate from the constant-head test based on calculated high and low infiltration rates is also presented.

All infiltration tests were concluded by shutting off the water source to the test basin and tracking the rate of pond level decline (herein referred to as a falling-head test). In one test basin with a low infiltration rate (Wildwood Creek at California Street), two falling-head tests were conducted. Differences in pond water levels recorded every hour during draining were used to calculate infiltration rates in units of feet/day based on an infiltrating area of the basin bottom footprint only. For test basins with very high infiltration rates, only one or two hourly measurements were recorded. In contrast, for test basins with low infiltration rates, up to 10 or more hourly measurements were recorded. The high and low infiltration rates calculated from the falling-head test are presented in Table 2. Infiltration rates calculated from the falling-head test are not considered as reliable as those calculated from constant-head tests due to the change in driving head when the basin is draining, but they do provide a good confirmation of the accuracy of metered flows during the constant-head test.

Table 2

Yucaipa Basin Infiltration Tests Results

Test Site	Adjacent Exploratory Boring	Test Start	Test End	Basin Dimensions			Test Basin Infiltrating Area		Total Infiltrated Water		Infiltration Rate Constant-Head Test			Infiltration Rate Falling-Head Test[c]	
				Length (ft)	Width (ft)	Ave. Pond Depth (ft)	Bottom Only (ft^2)	Bottom + Sidewalls (ft^2)	Gallons	Acre-Feet	High[a] (ft/d)	Low[b] (ft/d)	Average (ft/d)	High (ft/d)	Low (ft/d)
Tennessee Street Basins		7/9/2018	7/23/2018	32	30	2.5	960	1,270	871,782	2.68	12.3	9.2	10.8	11.1	9.5
Dunlap Channel		7/16/2018	7/30/2018	33	30	2.5	990	1,305	22,895	0.07	0.1	0.1	0.1	0.19	0.18
Chapman Heights Basin		7/23/2018	8/6/2018	37	33	2.5	1,221	1,571	974,084	2.99	11.5	8.8	10.2	9.5	7.3
10th Street and Avenue E	EX-7	7/30/2018	8/13/2018	39	36	2.1	1,404	1,719	1,451,335	4.45	13.4	12.0	12.7	11.5	9.8
Wildwood Creek at California Street	EX-5	8/6/2018	8/20/2018	42	21	2.5	882	1,197	270,060	0.83	4.0	2.9	3.5	3.1	2.4
Wilson Creek Basins	EX-1	8/13/2018	8/27/2018	32	29	3.0	928	1,294	882,120	2.71	8.7	6.1	7.4	7.4	5.5
City of Yucaipa at California Street	EX-5	8/20/2018	9/3/2018	33	32	3.0	1,056	1,446	1,646,180	5.05	18.5	13.6	16.0	16.8	14.5
Wilson Creek III	EX-3	8/27/2018	9/10/2018	45	20	2.0	900	1,160	3,426,110	10.51	59.2	44.8	52.0	N/A; too fast	
Oak Glen Creek Basins - Excavated	EX-2	9/3/2018	9/17/2018	32	32	2.5	1,024	1,344	1,974,600	6.06	24.1	17.9	21.0	19.7	19.7
Wildwood Creek Basins	EX-4	9/10/2018	9/24/2018	29	28	3.0	812	1,154	4,040,929	12.40	45.8	32.2	39.0	31.2	28.3
Oak Glen Creek Basins - Bermed	EX-2	9/17/2018	10/1/2018	34	34	1.6	1,156	1,374	639,130	1.96	6.1	5.2	5.6	6.6	5.2
Oak Glen Creek at Western Heights	EX-9	9/24/2018	10/1/2018	46	20	2.0	920	1,184	50,632	0.16	1.6	1.2	1.4	1.6	1.5

Notes:
a - High infiltration rate for constant-head test calculated based on infiltrating area equal to basin bottom only
b - Low infiltration rate for constant-head test calculated based on infiltrating area equal to basin bottom and sidewalls
c - Falling-Head Infiltration Rates calculated from measured water level decline based on infiltrating area of basin bottom only

It is recognized that in a homogeneous and unbounded vadose zone, measured infiltration rates for a field-scale test basin will be higher than infiltration rates for a full-scale basin due to a greater contribution of horizontal flow beneath the field-scale test basin. Additionally, physical clogging of a recharge basin is likely to reduce infiltration rates over time. These factors were considered to predict initial and long-term infiltration rates at each investigation site for a full-scale basin, as shown below in **Table 3**. Assumptions used to develop these estimates are described in more detail below.

Table 3

Estimated Initial and Long-Term Infiltration Rates for a Full-Scale Basin

Test Site	Adjacent Exploratory Boring	Constant-Head Field-Scale Infiltration Rate	Estimated Full-Scale Infiltration Rate	
		Average (ft/d)	Initial[a] (ft/d)	Long-Term[b] (ft/d)
Tennessee Street Basins		10.8	5.4	2.7
Dunlap Channel		0.1	0.1	0.03
Chapman Heights Basin		10.2	5.1	2.5
10th Street and Avenue E	EX-7	12.7	6.4	3.2
Wildwood Creek at California Street	EX-5	3.5	1.7	0.9
Wilson Creek Basins	EX-1	7.4	3.7	1.8
City of Yucaipa at California Street	EX-5	16.0	8.0	4.0
Wilson Creek III	EX-3	52.0	26.0	13.0
Oak Glen Creek Basins - Excavated	EX-2	21.0	10.5	5.2
Wildwood Creek Basins	EX-4	39.0	19.5	9.8
Oak Glen Creek Basins - Bermed	EX-2	5.6	2.8	2.8
Oak Glen Creek at Western Heights	EX-9	1.4	0.7	0.4

a - Initial Full-Scale Infiltration Rate is estimated to be 50 percent of average constant-head infiltration rate from field-scale testing to account for decreased horizontal flow component in full-scale test basin.

b - Long-Term Full-Scale Infiltration Rate is estimated to be 50 percent of the Initial Full-Scale Infiltration Rate to account for expected physical clogging of the basin bottom from SWP water. For "Oak Glen Creek Basins (EX-2) - Bermed", long-term infiltration rate is the same as initial full-scale infiltration rate, because the basin bottom is already significantly clogged. Actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.

The degree to which field-scale infiltration rates may overestimate full-scale basin infiltration rates is dependent on the relative difference in basin sizes. The future recharge basin area at each investigation site is currently unknown, and site-specific consideration was outside the scope of this study. For this study, a uniform factor of 50 percent is applied to infiltration rates from field-scale infiltration tests to predict infiltration rates in a full-scale recharge basin. This factor is recommended based on discussions with OCWD (Adam Hutchinson, Recharge Planning Manager, personal communication, November 7, 2018) and is applied to the average infiltration rate calculated from the constant-head test to provide an “initial” full-scale infiltration rate for each site (second-to-last column in Table 2). It is important to recognize that this scale-up factor does not account for the potential impacts to surface infiltration rates from possible low-permeability hydraulic boundary conditions (e.g., clay layers in the deeper vadose zone or clay gauge associated with nearby geologic faulting) that can inhibit radial flow of recharge water and increase recharge mounding beneath the recharge basin. Additional field investigations, such as pilot-scale infiltration testing, is needed to address the influence of hydraulic boundary conditions, including faults.

Accurate prediction of the effects of clogging on long-term infiltration rates in a full-scale recharge basin relies on a clear understanding of the site-specific recharge goal, anticipated active spreading period, and approach and frequency of basin maintenance. These factors are effectively unknown at this time. Recent research has improved the understanding of clogging dynamics to allow operators to reliably predict infiltration rate declines and optimize basin maintenance when site-specific information for active recharge basins are available. Key governing factors include the intrinsic permeability of sediments comprising the basin bottom and the suspended solids load in source water. A study by OCWD (Phipps, D.W., Lyon, S., and Hutchinson, A., 2007, see Appendix A) indicated that approximately 90 percent of the infiltration rate decline over time in selected OCWD basins were attributable to the accumulation of suspended solids mass on the basin floor and its interface with sediment on the basin floor.

The physical clogging potential of SWP water was recently characterized by Valley District by analyzing the total suspended solids (TSS) concentration of a sample collected from the Yucaipa Turnout of the SWP East Branch Extension. The TSS concentration of the SWP water was 1.4 mg/L, which is well below TSS concentrations of Santa Ana River water in the OCWD study. An additional clogging factor - algal growth - has also been observed in local SWP water recharge basins by the San Bernardino County Water Conservation District (SBCWCD) (personal communication, Richard Corneille, November 21, 2018). Basin design and operations will need to address long-term basin clogging through a combination of pre-treatment design solutions and a basin maintenance program.

For planning purposes, a “long-term” full-scale infiltration rate is predicted for all tests by reducing the initial full-scale infiltration rate by 50 percent. The 50 percent assumption accounts for currently unknown site-specific variables including the site recharge goal, active spreading period, and the frequency of basin maintenance over time.

3.1. Investigation Site Summaries

Conclusions integrating infiltration test results and local hydrogeologic conditions for each investigation site are presented along with recommendations for additional work below.

Generally, a site with favorable long-term recharge potential requires a combination of high surface infiltration rates and available land to construct a reasonable-sized recharge facility. A pilot-scale infiltration test is recommended if the size of a full-scale recharge project is significantly larger (e.g., 1 acre or more) than the field-scale test infiltration basin. Pilot testing will generally require excavation of a recharge basin commensurate in size with the intended full-scale recharge basin, conveyance and metering of test water sufficient to fill and maintain a constant-head, and accurate measurement of pond water levels. The pilot-scale infiltration test should be implemented over at least a 2 to 3-month period to identify potential site vadose zone storage capacity constraints, particularly if there are nearby geologic faults or hydraulic barriers. Installation of monitoring wells on both sides of a mapped fault or barrier is recommended to confirm groundwater levels beneath the site and the hydraulic connection across the fault/barrier during pilot recharge testing.

3.1.1. Tennessee Street Basin

A synopsis of the infiltration testing completed at the Tennessee Street Basin is shown on **Figure 2**. As shown on Figure 1, the site is located northwest of the Western Heights Subbasin, the northwestern boundary for which generally coincides with the Western Heights Fault. Despite its upgradient location relative to the Western Heights Subbasin and Western Heights Fault, the site is favorably located if recharge water can migrate below regional clay layers in the Western Heights Subbasin and replenish aquifers that support local groundwater production. No exploratory borings were drilled in 2014 near this site, and depth to groundwater is unknown.

Results of infiltration testing indicate that the site is suitable for recharge. The average infiltration rate from constant-head testing is 10.8 feet/day (based on stabilized rates observed after 9 days of testing), which is verified by measured infiltration rates from the falling-head test (9.5 to 11.1 feet/day).

A full-scale basin initial infiltration rate is predicted at 5.4 feet/day, and a full-scale long-term infiltration rate is predicted at 2.7 feet/day.

Pilot-scale infiltration testing involving installation of monitoring wells north and south of the Western Heights Fault is recommended, if the size of a potential full-scale recharge project is significantly larger than the existing storm detention basin.

3.1.2. Dunlap Channel

A synopsis of the infiltration testing completed at the Dunlap Channel is shown on **Figure 3**. As shown on the Figure 1, the site in the Western Heights Subbasin along the margins of a pumping depression centered approximately one mile east of the site. As shown on the cross section in the upper right corner of Figure 2 (modified from Geoscience 2014b), the site is underlain by thick and regionally extensive clay layers in the vadose zone. A nested USGS monitoring well (Dunlap Well) indicates that depth to groundwater in the area is about 400 feet-bgs.

Results of infiltration testing indicate that the site is not suitable for recharge. The average infiltration rate from constant-head testing is only 0.1 feet/day (based on stabilized rates observed after 4 days of testing), which is verified by measured infiltration rates from the falling-head test (0.18 to 0.19 feet/day).

Full-scale basin initial and long-term infiltration rates are predicted to be less than 0.1 feet/day.

Development of a recharge facility and any additional investigations are not recommended at this site.

3.1.3. Chapman Heights Basin

A synopsis of the infiltration testing completed at the Chapman Heights Basin is shown on **Figure 4**. As shown on Figure 1, and similar to the Tennessee Street Basin site, this site is located north of the Western Heights Subbasin, the northwestern boundary which generally coincides with the Western Heights Fault. Despite its upgradient location relative to the Western Heights Subbasin and Western Heights Fault, the site is favorably located if recharge water can migrate below regional clay layers in the Western Heights Subbasin and replenish aquifers that support local groundwater production. No exploratory borings were drilled in 2014 near this site, and depth to groundwater is unknown.

Results of infiltration testing indicate that the site is suitable for recharge. The average infiltration rate from constant-head testing is 10.2 feet/day (based on stabilized rates observed after approximately 9 days of testing), which is generally verified by measured infiltration rates from the falling-head test (7.3 to 9.5 feet/day). The cause of the slight decline in infiltration rate after Day 10 is unknown, it but does not appear to be significant.

A full-scale basin initial infiltration rate is predicted at 5.1 feet/day, and a full-scale long-term infiltration rate is predicted at 2.5 feet/day.

Pilot-scale infiltration testing involving installation of monitoring wells north and south of the Western Heights Fault is recommended, if the size of a potential full-scale recharge project is significantly larger than the existing storm detention basin.

3.1.4. 10th Street and avenue E (EX-7)

A synopsis of the infiltration testing completed at the 10th Street and Avenue E Basin is shown on **Figure 5**. As shown on Figure 1, this site straddles the Western Heights and Calimesa Subbasin boundary, which coincides with the northeast-trending Chicken Hills Fault. The potential value of this site for recharge is contingent on the hydraulic connection between the Calimesa Subbasin and the Western Heights Subbasin across the Chicken Hill Fault. The relative location and proximity of the site to several mapped traces of the Chicken Hills Fault to the west/northwest indicate that groundwater replenishment benefits may be limited to the downgradient portion of the Calimesa Basin. Exploratory boring EX-7 was drilled in 2014 south of Avenue E and the test site. Depth to groundwater was measured at

115 feet-bgs, similar to water levels east of the fault in the Calimesa Subbasin, and 300 feet higher than in the Western Heights Subbasin, indicating that the hydraulic connection between the site and Western Heights Subbasin is likely poor.

Results of infiltration testing indicate that the site is suitable for recharge. The average infiltration rate from constant-head testing is 12.7 feet/day (based on relatively stabilized rates observed after 12 days of testing), which is generally verified by measured infiltration rates from the falling-head test (9.8 to 11.5 feet/day).

A full-scale basin initial infiltration rate is predicted at 6.4 feet/day, and a full-scale long-term infiltration rate is predicted at 3.2 feet/day.

Pilot-scale infiltration testing involving installation of monitoring wells west and east of the Chicken Hills Fault is recommended, if the size of a potential full-scale recharge project is significantly larger than the existing storm drainage area.

3.1.5. Wildwood Creek at California Street (EX-5)

A synopsis of the infiltration testing completed at the Wildwood Creek at California Street is shown on **Figure 6**. The site in the eastern portion of the Calimesa Subbasin with no nearby geologic faults. Based on the lithologic log of exploratory boring EX-5 located about 400 feet to the southeast, the site is underlain by generally permeable sand and gravel deposits. Only a few minor clay layers were observed in the vadose zone. Depth to water in YRP- EX-5 was 342 feet-bgs in 2014.

Results of infiltration testing indicate that the site is not suitable for recharge. The average infiltration rate from constant-head testing is 3.5 feet/day (based on stabilized rates observed almost immediately after the start of testing), which is verified by measured infiltration rates from two falling-head tests (2.4 to 3.1 feet/day).

Full-scale basin initial and long-term infiltration rates are predicted to be less than 1.7 and 0.9 feet/day, respectively. Low infiltration rates appear to be due to a clayey silt layer, the top of which occurs at a depth of 10 to 12 feet below the channel floor. Dry soil conditions were observed below the clayey silt layer at the end of testing. The fine-grained material may be associated with sediment load from natural stormflows.

Surficial coarse-grained sands and gravels on the surface of Wildwood Creek at California Street appear to have limited thickness and are underlain by a fine-grained matrix that significantly limits infiltration. Development of a recharge facility and additional investigations are not recommended at this site.

3.1.6. Wilson Creek Basins

A synopsis of the infiltration testing completed at the Wilson Creek Basins is shown on **Figure 7**. As shown on Figure 1, the site is located in the upgradient portion of the Basin in the center of the Gateway Subbasin. The Chicken Hill Fault is located north of the site, but based on local groundwater levels, does not appear to represent a subsurface barrier to groundwater flow. Based on the lithologic log of exploratory boring EX-1 located on the berm 450 feet to the southwest, the site is underlain by coarse-grained deposits; however, shallow fine-grained (clay) deposits create perched conditions beneath the basins during recharge and limit surface infiltration rates. Such conditions were observed both during pilot-scale infiltration test by the USGS in 1970 and during field-scale testing. Depth to water in PZ-1 (constructed in EX-1) was 272 feet-bgs in 2014.

Results of infiltration testing confirm that the site is suitable for recharge. The average infiltration rate from constant-head testing is 7.4 feet/day (based on relatively stabilized rates observed after 11 days of testing), which is verified by measured infiltration rates from the falling-head test (5.5 to 7.4 feet/day). The "high" infiltration rate (based on an infiltrating area of the basin bottom only) matches the final infiltration rate achieved by the USGS in 1970 of about 9 feet/day. The USGS-reported rate and rates from field-scale testing are considered representative of a "clean" basin.

A full-scale basin initial infiltration rate is predicted at 3.7 feet/day, and a full-scale long-term infiltration rate is predicted at 1.8 feet/day.

If site recharge goals are expected to exceed the operational capacity of the basins based on predicted long-term rates, the removal of the upper approximately 3 feet of sediment in each of the basins prior to resumption of active recharge is recommended. Pilot-scale testing is not recommended at this site.

3.1.7. City of Yucaipa at California Street (EX-5)

A synopsis of the infiltration testing completed at the Wildwood Creek at California Street is shown on **Figure 8**. The site in the eastern portion of the Calimesa Subbasin with no nearby geologic faults. Based on the lithologic log of exploratory boring EX-5, located about 100 feet to the southeast, the site is underlain by generally permeable sand and gravel deposits. Only a few minor clay layers were observed in the vadose zone. Depth to water in EX-5 was 342 feet-bgs in 2014.

Results of infiltration testing indicate that the site is highly suitable for recharge. The average infiltration rate from constant-head testing is 16.0 feet/day (based on stabilized rates observed after 4 days of testing), which is verified by measured infiltration rates from the falling-head test (14.5 to 16.8 feet/day).

A full-scale basin initial infiltration rate is predicted at 8.0 feet/day, and a full-scale long-term infiltration rate is predicted at 4.0 feet/day.

Pilot-scale infiltration testing is recommended, assuming a full-scale recharge basin would include the majority of the land parcel. No new monitoring wells are needed. However, monitoring of water levels in the nested USGS Equestrian well, located just east of California Street and north of Avenue G, is recommended during pilot testing.

3.1.8. Wilson Creek III (EX-3)

A synopsis of the infiltration testing completed at the Wilson Creek III is shown on **Figure 9**. The site in the eastern portion of the Gateway Subbasin. Based on the lithologic log of exploratory boring EX-3 located about 900 feet to the east, the site is underlain by permeable sand and gravel deposits. Only a few minor silt layers were observed in the vadose zone. Depth to water in EX-3 was 202 feet-bgs in 2014.

Results of infiltration testing indicate that the site is highly suitable for recharge. The average infiltration rate from constant-head testing is 52 feet/day (based on relatively stabilized rates observed after 10 days of testing). It is possible that rates may be overestimated due to the proximity of the test basin to a large-diameter conveyance pipe along the east side of 2nd St, set in a gravel-filled trench. Because the basin drained within a couple of hours, an infiltration rate from the falling-head test could not be calculated.

A full-scale basin initial infiltration rate is predicted at 26.0 feet/day, and a full-scale long-term infiltration rate is predicted at 13.0 feet/day.

Pilot-scale infiltration testing involving installation of monitoring wells north and south of the Chicken Hill Fault is recommended, if the size of a potential full-scale recharge project is significantly larger than the test basin. Monitoring of water levels in the nearby YVWD production well located south of the test site may preclude the need for a monitoring well south of the Chicken Hill Fault if the well is not actively pumped during pilot testing.

3.1.9. Oak Glen Creek Basins (Excavated) (EX-2)

A synopsis of the infiltration testing completed at the Oak Glen Creek Basins (excavated) is shown on **Figure 10**. The site is favorably located upgradient of major production wells in the Gateway and Wilson Creek subbasins. Water levels indicate that recharging at this location will likely benefit aquifers on both sides of the Chicken Hill Fault. Based on the lithologic log of exploratory boring EX-2 located about 200 feet to the east, the site is underlain by coarse-grained deposits that allow for uninhibited vertical migration of recharge water to the underlying water table, which is at 302 ft-bgs in 2014).

Results of infiltration testing indicate that the site is highly suitable for recharge. The average infiltration rate from constant-head testing is 21.0 feet/day (based on stabilized rates observed after one day of testing), which is verified by measured infiltration rates from the falling-head test (19.7 feet/day). An apparent decline in infiltration rate was observed from Day 9 through Day 11 of testing. This is believed to be related to a pressure drop in the fire hydrant, which resulted in pond water levels gradually dropping over this period as well.

A full-scale basin initial infiltration rate is predicted at 10.5 feet/day, and a full-scale long-term infiltration rate is predicted at 5.2 feet/day. This rate assumes historically accumulated silt/clay in the upper 3 feet of the basin is removed, and a basin maintenance plan is established.

If site recharge goals are expected to exceed the operational capacity of the basins, we recommend the removal of the upper 3 feet of sediment in each of the basins prior to future active recharge. Pilot-scale testing is not critical at this site.

3.1.10. Wildwood Creek Basins (EX-4)

A synopsis of the infiltration testing completed at the Wildwood Creek Basins is shown on **Figure 11**. The site is located in the Oak Glen Creek Subbasin upgradient of the South Mesa barrier and aquifers in the Calimesa Subbasin relied upon for groundwater production. The site is underlain by highly permeable deposits that should allow for uninhibited vertical migration of recharge water to the underlying water table. Available vadose zone storage may be limited by the existing depth to water (104 feet-bgs in MW-3 [constructed in EX-4] in 2014) located about 140 feet to the east. The degree to which recharge water can flow across the South Mesa Barrier into the Calimesa Subbasin is a critical knowledge gap that requires further investigation and/or evaluation.

Results of infiltration testing indicate that the site is highly suitable for recharge. The average infiltration rate from constant-head testing is 39.0 feet/day (based on stabilized rates observed after 9 days of testing), which is generally verified by measured infiltration rates from the falling-head test (28.3 to 31.2 feet/day). Lower rates from the falling-head test are likely due to less driving head from declining water levels.

A full-scale basin initial infiltration rate is predicted at 19.5 feet/day, and a full-scale long-term infiltration rate is predicted at 9.8 feet/day.

Pilot-scale infiltration testing is recommended to identify potential site vadose zone storage capacity constraints due to associated recharge mounding, which may be exacerbated by the South Mesa Barrier. Installation of a monitoring well west of the South Mesa Barrier and monitoring of water levels in the new monitoring well and MW-3 during pilot testing is recommended to better understand the subsurface flow dynamics across the South Mesa Barrier.

3.1.11. Oak Glen Creek Basins (Bermed) (EX-2)

A synopsis of the infiltration testing completed at the Oak Glen Creek Basins (bermed) is shown on **Figure 12**. This site is unique, in that native material was used to create shallow berms to test the infiltration through undisturbed sediment at the ground surface. The site is favorably located upgradient of major production wells in the Gateway and Wilson Creek subbasins. Water levels indicate that recharging at this location will likely benefit aquifers on both sides of the Chicken Hill Fault. Based on the lithologic log of exploratory boring EX-2 located about 200 feet to the east, the site is underlain by coarse-grained deposits that allow for uninhibited vertical migration of recharge water to the underlying water table, which is at 302 ft-bgs in 2014).

Results of infiltration testing, combined with the results from the excavated test basin (see section 3.1.9), indicate that while the site is highly suitable for recharge, accumulated sediments to about 3 feet in depth have a significant negative impact on infiltration rates. The average infiltration rate from constant-head testing is 5.6 feet/day (based on stabilized rates observed after one day of testing), which is verified by measured infiltration rates from the falling-head test (5.2 to 6.6 feet/day).

For the bermed test, full-scale initial and long-term infiltration rates of 2.8 feet/day are predicted, as the existing basin is currently clogged. The estimated long-term infiltration rate is similar to the infiltration rate of 3.2 feet/day measured for the middle basin during pilot-scale testing of the Oak Glen Creek Basins in 2017-2018 (City of Yucaipa et al., 2018).

If site recharge goals are expected to exceed the operational capacity of the Oak Glen Creek Basins, the removal of the upper 3 feet of sediment in each of the Oak Glen Creek basins prior to future active recharge is recommended. Pilot-scale testing is not critical at this site.

3.1.12. Oak Glen Creek at Western Heights (EX-9)

A synopsis of the infiltration testing completed at the Oak Glen Creek Basins at Western Heights is shown on **Figure 13**. The site in the center of the Western Heights Subbasin. Based on the lithologic log of exploratory boring EX-9 located along the northern channel bank about 550 feet to the northwest, the site is generally underlain by permeable sand and gravel deposits. Fine-grained deposits were identified in EX-9 from 15 to 25 feet-bgs (approximately 0 to 10 feet below the channel bottom); however, fine-grained material observed during excavation of the test basin indicated significant fine-grained sediment load from natural stormflows. Depth to water in EX-9 was measured at 347 feet-bgs in 2014.

Results of infiltration testing indicate that the site is not suitable for recharge. The average infiltration rate from constant-head testing is 1.4 feet/day (based on stabilized rates observed almost immediately after the start of testing), which is verified by measured infiltration rates from two falling-head tests (1.5 to 1.6 feet/day).

Full-scale basin initial and long-term infiltration rates are predicted to be less than 0.7 and 0.4 feet/day, respectively. Low infiltration rates appear to be associated with fine-grained geologic deposits and associated with sediment loads from stormflows. Development of a recharge facility and any additional investigations are not recommended at this site.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1. CONCLUSIONS

Based on the results of infiltration testing completed at eleven investigation sites in the Yucaipa Basin, the following general conclusions can be made:

- Short-term infiltration testing using temporary field-scale basins provides a reliable and cost-effective means for confirming vadose zone infiltration capacity, a critical component to assessing site recharge feasibility.
- Infiltration test results provide a technical basis for predicting “initial” infiltration rates for a full-scale recharge basin, the size for which is known at existing storm detention/recharge facilities (e.g., Wilson Creek Basins, Oak Glen Creek Basins, and Wildwood Creek Basins) and unknown for other sites.
- Initial full-scale infiltration rates presented herein do not account for potential hydraulic boundary conditions that can inhibit radial flow of recharge water and increase recharge mounding beneath a full-scale recharge basin. The primary boundary condition concern identified for some investigation sites is the presence of a nearby geologic fault or barrier. Additional focused field investigations, including pilot-scale infiltration testing with groundwater monitoring, are needed to address these effects.
- Infiltration test results also provide a technical basis for predicting “long-term” infiltration rates for a full-scale basin, needed to support future evaluation and design of recharge facilities to optimize groundwater water level, storage, safe yield, and water quality benefits in the Yucaipa Basin. Long-term full-scale infiltration rates presented herein consider the effects of basin clogging which is dependent on currently unknown variables, including the site-specific recharge goals, anticipated active spreading period, and approach and frequency of basin maintenance.

Combined with existing available hydrogeologic information, infiltration test results indicate the following regarding site recharge feasibility, organized below by subbasin:

Western Heights Subbasin

The Tennessee Street Basins and Chapman Heights Basins appear to provide adequate infiltration capacity (predicted long-term rates of 2.7 and 2.5 feet/day, respectively). Both sites are favorably located upgradient of aquifers relied upon for groundwater production and beyond the extent of regionally extensive clay layers in the Western Heights Subbasin. Whether the migration of recharge water across the Western Heights Fault into the Western Heights Subbasin will be inhibited represents a critical knowledge gap that requires further investigation and/or evaluation.

Very low infiltration rates associated with fine-grained vadose zone sediments were measured at the Oak Glen Creek at Western Heights and Dunlap Channel sites (predicted long-term rates of 0.4 and 0.03 feet/day). A further complication and challenge of operating an in-channel recharge facility is the need for potentially frequent basin maintenance to remove debris associated with storm events that may further reduce surface infiltration rates.

Calimesa/Oak Glen Subbasins

The City of Yucaipa at California Street site appears to provide the best combination of infiltration capacity (predicted long-term rate of 4.0 feet/day) and location from a hydrogeologic perspective. The site is favorably located upgradient of key production wells in the Calimesa Subbasin and is underlain by coarse-grained deposits that should allow for uninhibited vertical migration of recharge water to the underlying water table (342 ft-bgs in 2014). The site is also located a significant distance from geologic faults that form most of the boundaries of the Calimesa Subbasin.

The Wildwood Creek Basins provides a high infiltration capacity (predicted long-term rate of 9.8 feet/day). The site is located in the Oak Glen Creek Subbasin upgradient of aquifers in the Calimesa Subbasin relied upon for groundwater production. The site is underlain by highly permeable deposits that should allow for uninhibited vertical migration of recharge water to the underlying water table. Available vadose zone storage may be limited by the existing depth to water of approximately 100 feet-bgs. The degree to which recharge water can flow across the South Mesa Barrier into the Calimesa Subbasin is a critical knowledge gap that requires further investigation and/or evaluation.

The 10th Street at Avenue E site appears to provide a good infiltration capacity (predicted long-term rate of 3.2 feet/day). Clay sediments found in nearby exploratory borehole EX-7 (south of Avenue E outside of the channel) down to 25 feet-bgs were not encountered during test basin excavation. Despite having good infiltration capacity, the site is poorly located adjacent to and east of the Chicken Hill Fault in the Calimesa Subbasin. The potential value of this site for recharge is contingent on potential benefits this site can provide to the Western Heights Subbasin. Water level differences of approximately 300 feet across the Chicken Hill Fault indicate that the hydraulic connection between the site and Western Heights Subbasin is expected to be poor. However, further investigation and/or evaluation is needed to confirm this interpretation.

Low infiltration rates associated with shallow fine-grained sediments were measured at the Wildwood Creek at California Street site (predicted long-term rate of 0.9 feet/day). Similar to the challenges identified for the two channel sites in the Western Heights Subbasin, operating an in-channel recharge facility could potentially frequent basin maintenance to remove debris associated with storm events.

Gateway/Wilson Creek Subbasins

Of the two existing storm detention/recharge basins in this area, the Oak Glen Creek Basins appears to provide the best infiltration capacity on a per-acre basis. The predicted long-term rate for the middle basin tested is 5.2 feet/day. This rate assumes historically accumulated silt/clay in the upper 3 feet of the basin is removed, and a basin maintenance plan is established. From a hydrogeologic perspective, the site is favorably located upgradient of major production wells in the Gateway and Wilson Creek subbasins. Water levels indicate that recharging at this location should benefit aquifers on both sides of the Chicken Hill Fault. The site is underlain by coarse-grained deposits that should allow for uninhibited vertical migration of recharge water to the underlying water table, which was at 302 ft-bgs in 2014.

The Wilson Creek Basins provides a reasonable infiltration capacity (predicted long-term rate of 1.8 feet/day, assuming historically accumulated silt/clay in the upper 2-3 feet of the basin is removed). From a hydrogeologic perspective, the site is favorably located upgradient of major production wells in the Gateway Subbasin. Recharging at this location has historically benefited areas on both sides of the Chicken Hill Fault. The site is primarily underlain by coarse-grained deposits; however, shallow fine-grained (clay) deposits create perched conditions beneath the basins during recharge and limit surface infiltration rates. Such conditions were observed both during pilot-scale infiltration test by the USGS in 1970 and during field-scale testing. Accordingly, for this site, the long-term infiltration rate of 1.8 feet/day accounts not only for long-term clogging, but also for predicted mounding (given the results are similar to the 1970 pilot test, which identified the shallow perching condition).

The Wilson Creek III site provides an exceptionally high infiltration capacity (predicted long-term rate of 13.0 feet/day). While the site is underlain by highly permeable sand and gravel deposits that should allow for uninhibited vertical migration of recharge water to the underlying water table, measured infiltration rates may be slightly overestimated due to the presence of a gravel-filled trench next to the site. The site is located in the Gateway Subbasin upgradient of aquifers relied upon for groundwater production. Available vadose zone storage is sufficient based on a 2014 measured depth to water of 202 feet-bgs. Recharging at this location would likely yield benefits both south and north of the Chicken Hill Fault. Confirmation of the infiltration rate for a full-scale basin requires further investigation.

4.2. Recommendations

Key findings from this study are based on integration of infiltration testing results with available site-specific and basin-wide hydrogeologic information. We recommend that Valley District and its partners use the long-term infiltration rates presented in this report to quantify potential groundwater level/storage benefits from recharge and establish site-specific recharge goals that maximize basin yield while meeting subbasin and basin sustainability criteria as part of the GSP development process. We envision these tasks will be an iterative process utilizing the Yucaipa Basin groundwater flow model developed by the USGS.

Depending on the modeling results and sustainability criteria established, we recommend performing pilot-scale infiltration testing at preferred investigation sites to fill critical knowledge gaps and support implementation of a basin recharge program. Pilot-scale infiltration tests will require excavation of a recharge basin commensurate in size with the full-scale recharge basin, conveyance and metering of test water sufficient to fill and maintain a constant-head, and accurate measurement of pond water levels. Recommended actions for each investigation site are summarized below followed by site-specific details.

Table 4

Recommended Future Investigation/Testing Activities

Test Site	Adjacent Exploratory Boring	Estimated Long-Term Infiltration Rate (ft/d)	Recommended Action		
			Pilot Testing[1]	New Monitoring Well(s)	Basin Cleaning[2]
Tennessee Street Basins		2.7	Yes	Yes	
Dunlap Channel		0.0	No	No	
Chapman Heights Basin		2.5	Yes	Yes	
10th Street and Avenue E	EX-7	3.2	Yes	Yes	
Wildwood Creek at California Street	EX-5	0.9	No	No	
Wilson Creek Basins	EX-1	1.8	No	No	Yes
City of Yucaipa at California Street	EX-5	4.0	Yes	No	
Wilson Creek III	EX-3	13.0	Yes	Yes	
Oak Glen Creek Basins	EX-2	5.2	No	No	Yes
Wildwood Creek Basins	EX-4	9.8	Yes	Yes	
Oak Glen Creek at Western Heights	EX-9	0.35	No	No	

Notes:
1 - Recommended pilot testing assumes recharge will help to achieve basin/subbasin sustainability goals.
2 - Basin cleaning is recommended at the Wilson Creek Basins and Oak Glen Creek Basins if site recharge goals are expected to exceed the current operational capacity of the basins.

Western Heights Subbasin

Tennessee Street Basins / Chapman Heights Basins: Depending on the size of the full-scale basin, pilot-scale infiltration testing is recommended to identify potential site vadose zone storage capacity constraints due to recharge mounding and benefits to the Western Heights Subbasin. Installation of monitoring wells north and south of the Western Heights Fault is recommended to confirm groundwater levels beneath the sites and to better understand the hydraulic connection to the Western Heights Subbasin.

Calimesa/Oak Glen Subbasins

City of Yucaipa at California Street: Pilot-scale infiltration testing is recommended to confirm initial full-scale infiltration rates and identify potential site vadose zone storage capacity constraints due to recharge mounding. Installation of one monitoring well adjacent to the pilot basin is recommended to confirm arrival of recharge water at the water table (which is relatively deep at 342 feet-bgs) and monitor future groundwater level changes.

Wildwood Creek Basins: Pilot-scale infiltration testing is recommended to identify potential site vadose zone storage capacity constraints due to associated recharge mounding, which may be exacerbated by the South Mesa Barrier. Installation of a monitoring well west of the South Mesa Barrier and monitoring of water levels during pilot testing is recommended to better understand the subsurface flow dynamics across the South Mesa Barrier.

10th Street and Avenue E: Water level differences of approximately 300 feet across the Chicken Hill Fault indicate that the hydraulic connection between this site and the Western Heights Subbasin is likely to be poor. However, further investigation is needed to confirm this interpretation. If there is interest in developing a recharge facility at this site, pilot-scale infiltration testing is recommended with installation of a monitoring well east and west of the Chicken Hill Fault.

Gateway/Wilson Creek Subbasins

Oak Glen Creek Basins: If site recharge goals are expected to exceed the operational capacity of the basins, we recommend the removal of the upper 3 feet of sediment in each of the basins prior to future active recharge. Pilot-scale testing is not critical at this site.

Wilson Creek Basins: If site recharge goals are expected to exceed the operational capacity of the basins, we recommend the removal of the approximately upper 3 feet of sediment in each of the basins prior to future active recharge. Pilot-scale testing is not recommended at this site.

Wilson Creek III: Depending on the size of the full-scale basin, pilot-scale infiltration testing is recommended to confirm full-scale initial infiltration rates and to identify potential site vadose zone storage capacity constraints due to recharge mounding. Installation of a monitoring well adjacent to the site is recommended to confirm the arrival and mounding effect of recharge water during pilot testing and to track future groundwater level changes.

5. REFERENCES

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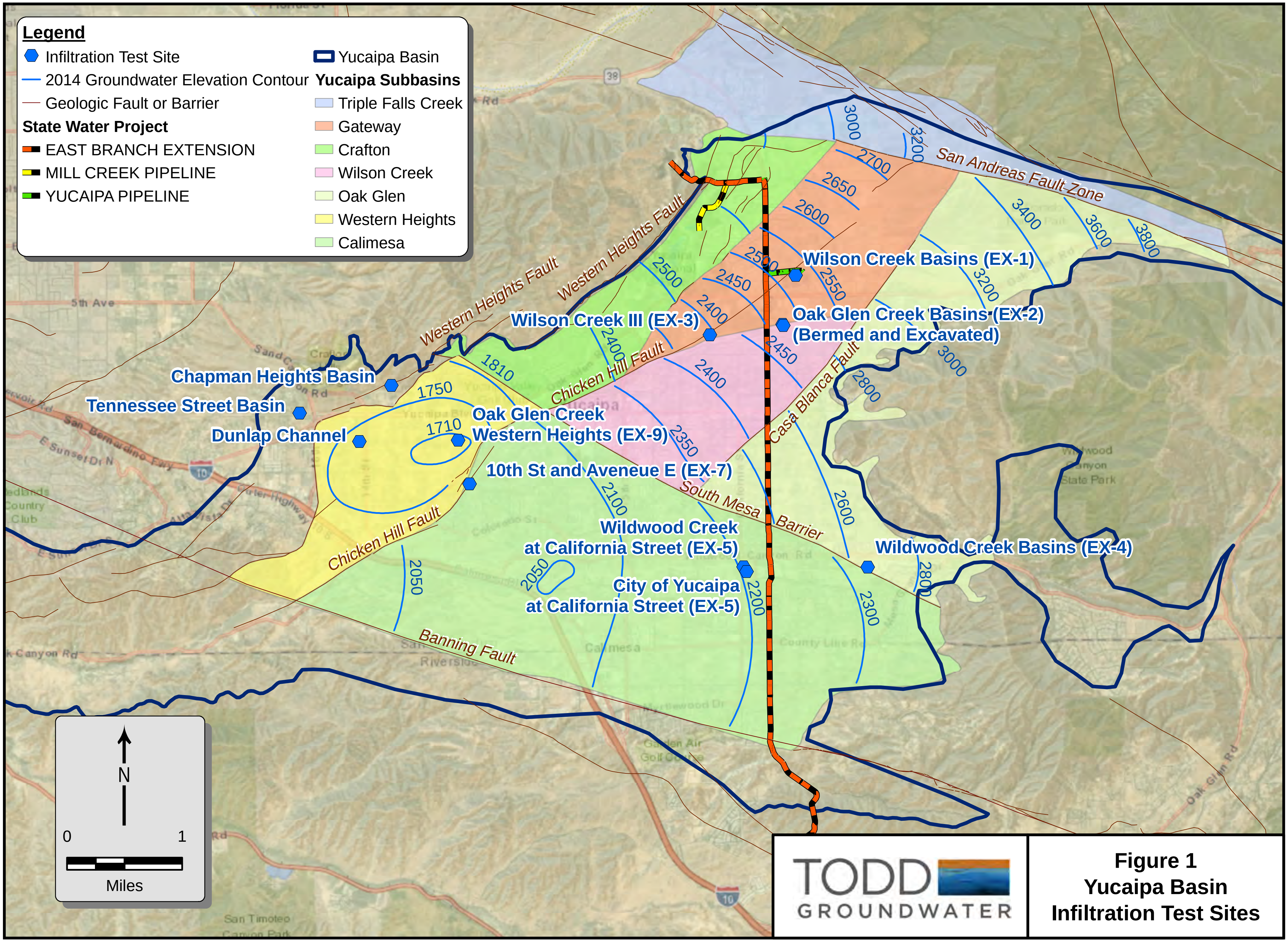
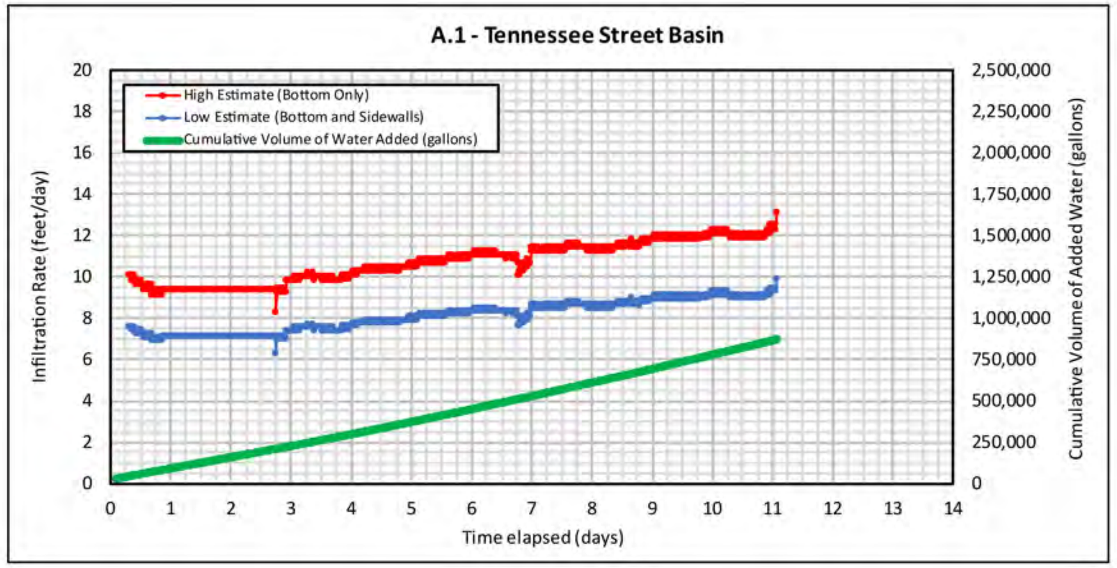
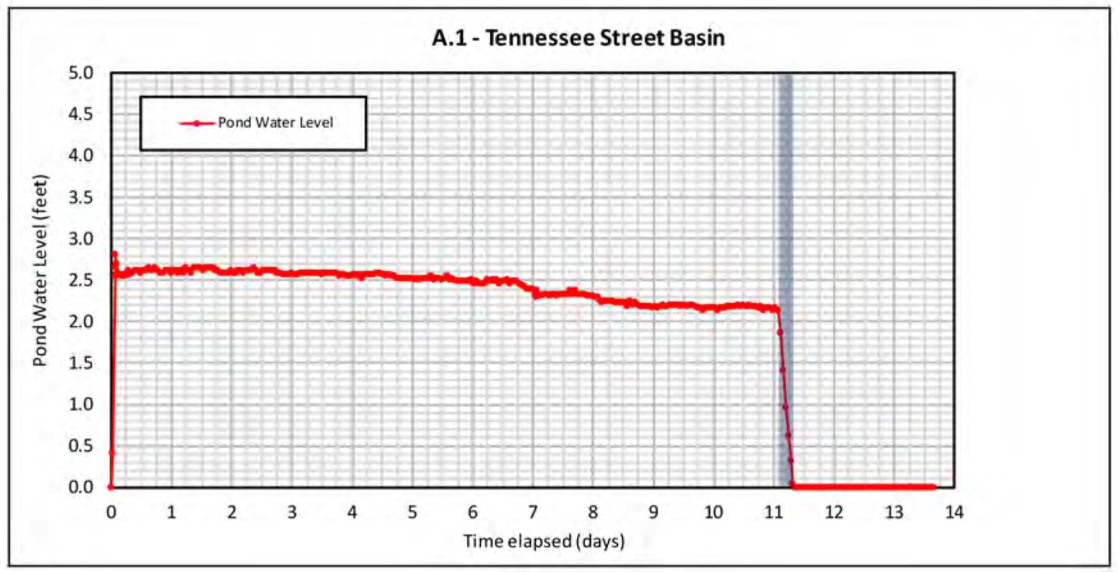


Figure 1
Yucaipa Basin
Infiltration Test Sites

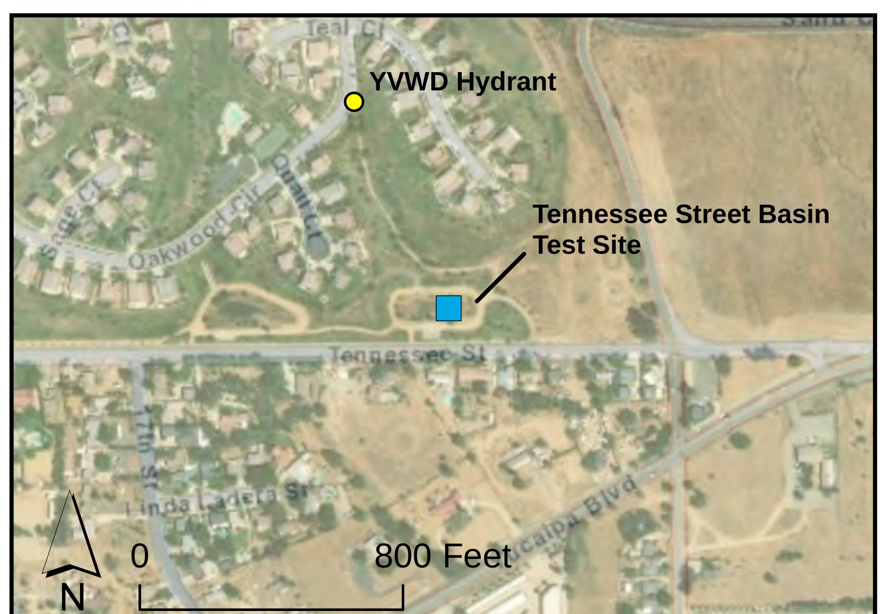
Infiltration Test Results





A. YVWD hydrant setup at Oakwood Circle
B. 4" fire hose above test site
C. Setting up flow control skid in excavation prior to filling; two float valves on 2" discharge lines and high and low water level alarm sensors
D. Initial fill of test basin (Day 1)
E. Consistent silt with fine to medium sand (0-5 feet)

Test Start		Jul-09-2018
Test End		Jul-23-2018
Basin Dimensions (L x W) (ft)		32 x 30
Average Water Height (ft)		2.5
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		871,782
Total Water Added (acre-feet)		2.7
Infiltration Rate (Constant-Head)	High (ft/d)	12.3
	Low (ft/d)	9.2
	Average (ft/d)	10.8
Infiltration Rate (Falling-Head)	High (ft/d)	11.1
	Low (ft/d)	9.5
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		5.4
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		2.7



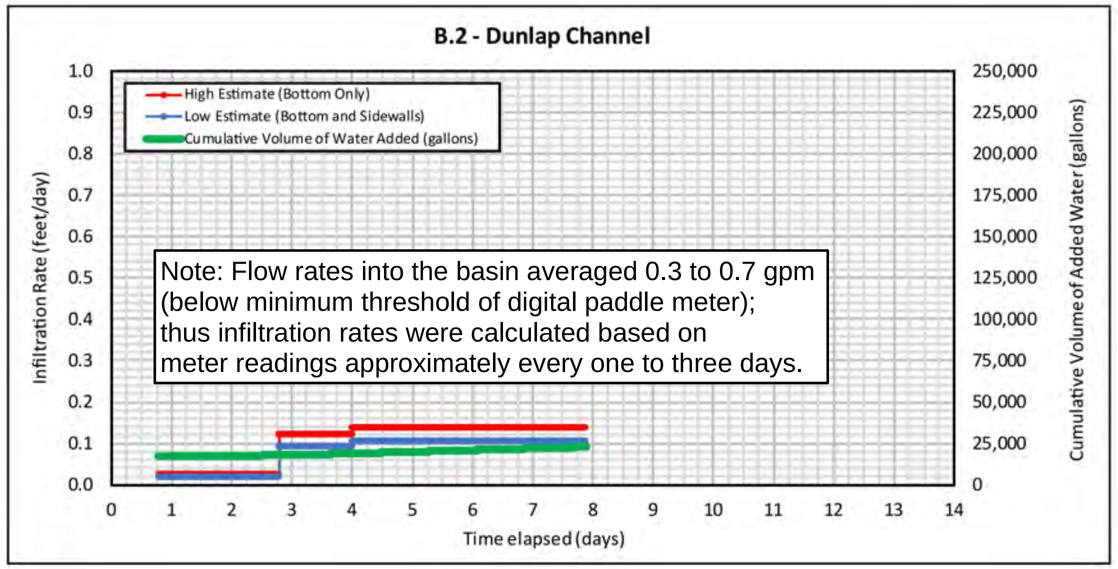
Conclusions:
- Results of infiltration testing indicate that the site is suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 5.4 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 2.7 feet/day. While long-term estimates consider expected clogging of the basin bottom from SWP water, actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.

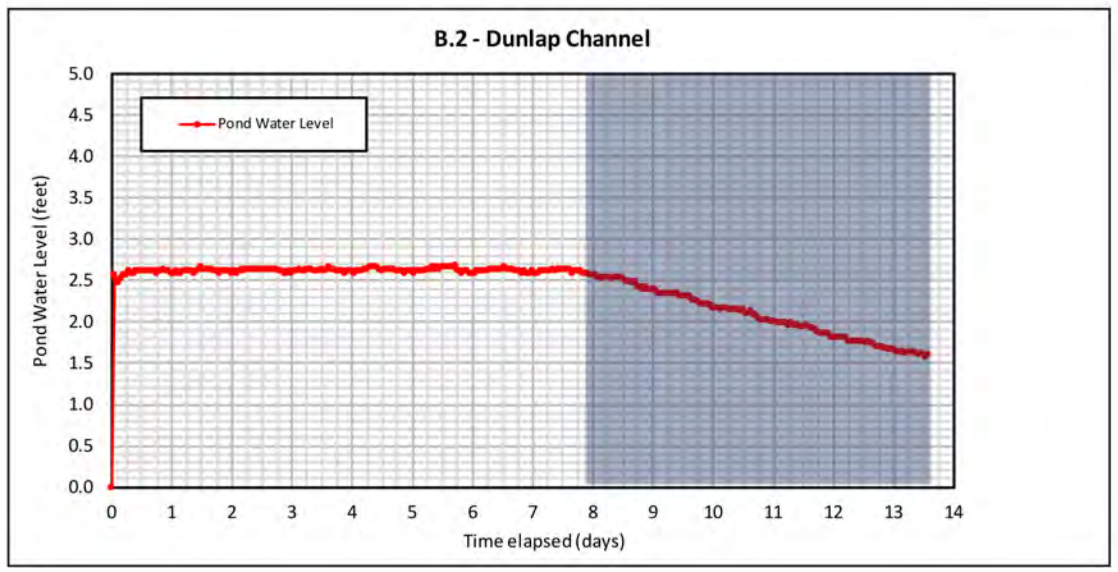
Recommendations:
- Depending on size of a full-scale recharge project, pilot scale infiltration test is recommended to identify potential site vadose zone storage capacity constraints due to recharge mounding.
- Pilot testing combined with installation of monitoring wells north and south of the Western Heights Fault is recommended to confirm groundwater storage benefits from recharge at this location.

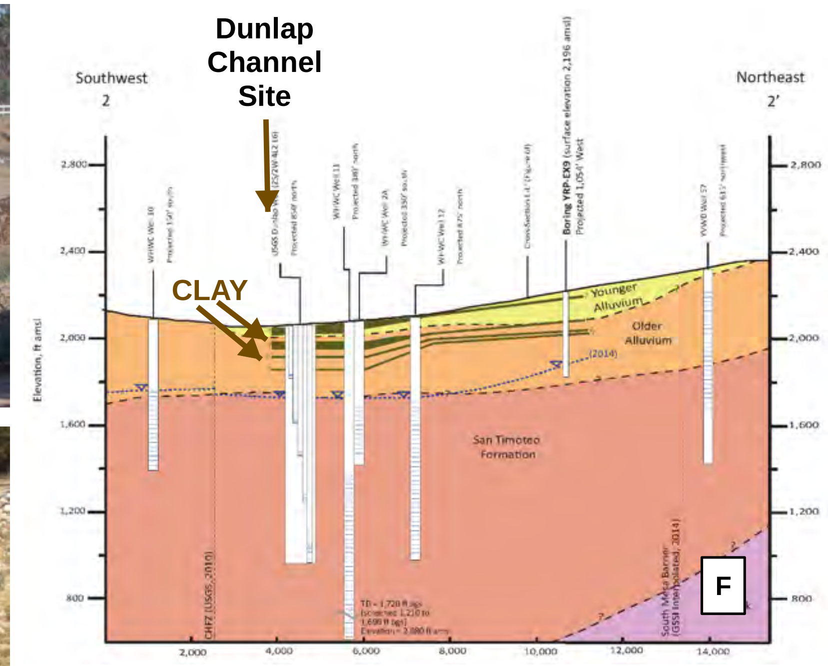
TODD GROUNDWATER

Figure 2
Tennessee Street Basin

Infiltration Test Results







A. WHWC hydrant setup on Avenue D
B. Excavation of test infiltration basin
C. Native clay sediment deposited on base of flow control skid at end of testing (Day 13)
D. Testing in progress (Day 1)
E. End of falling-head test (Day 13)
F. Geologic cross section 2-2' (Figure 5b; Geoscience, Dec 2014) showing significant clay lenses in vadose zone beneath Dunlap Channel test basin site

Test Start		Jul-16-2018
Test End		Jul-30-2018
Basin Dimensions (L x W) (ft)		33 x 30
Average Water Height (ft)		2.5
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		22,895
Total Water Added (acre-feet)		0.1
Infiltration Rate (Constant-Head)	High (ft/d)	0.14
	Low (ft/d)	0.1
	Average (ft/d)	0.1
Infiltration Rate (Falling-Head)	High (ft/d)	0.19
	Low (ft/d)	0.18
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		0.1
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		0.0

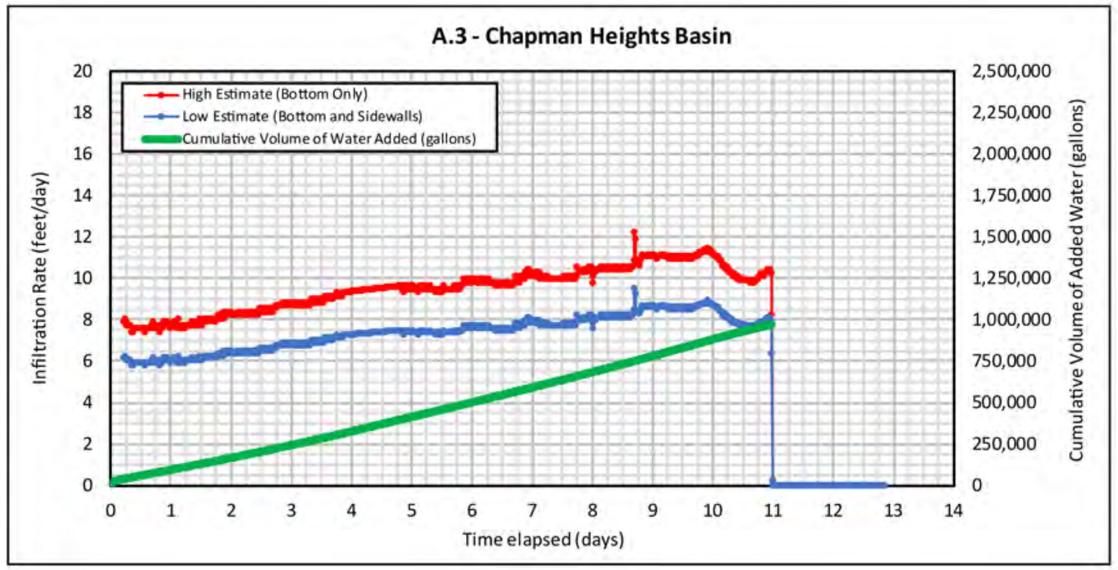
Conclusions:
- Results of infiltration testing indicate that the site is not suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 0.1 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at <0.1 feet/day.

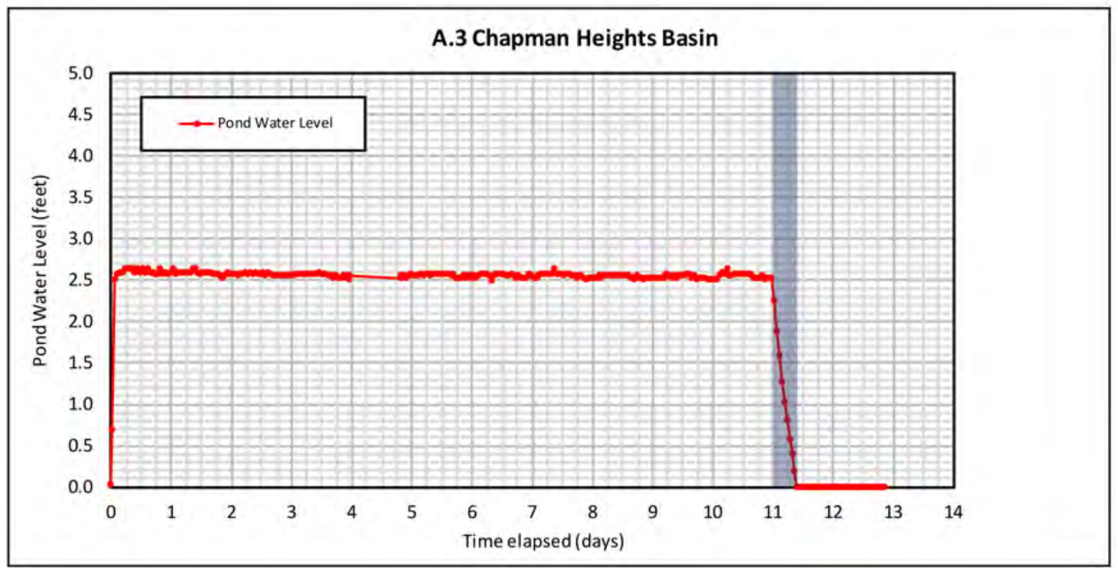
Recommendations:
- Regional geologic cross sections and interpretations indicate vadose zone sediments are comprised of significant fine-grained clay layers in this area of the Western Heights Subarea, corresponding with the very low infiltration rates observed during testing.
- No additional actions are recommended at this site.

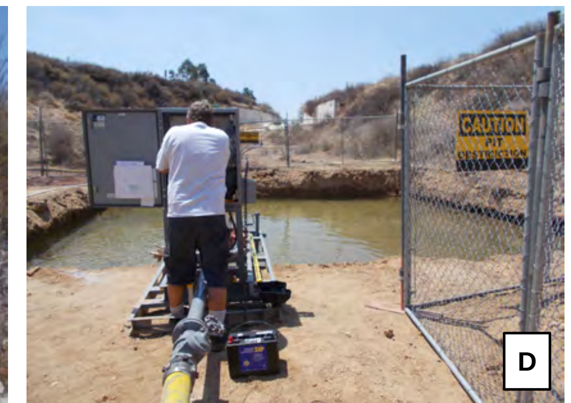
TODD GROUNDWATER

Figure 3
Dunlap Channel

Infiltration Test Results

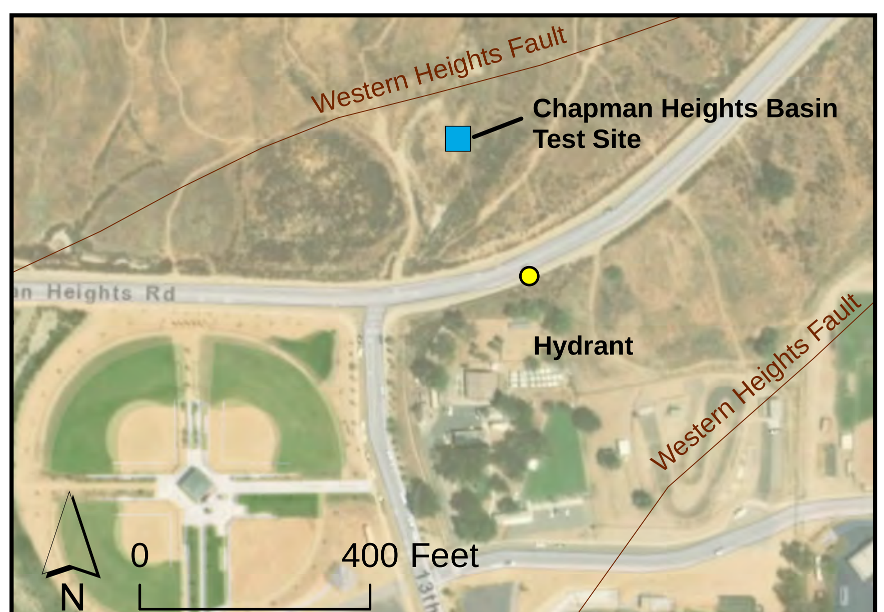






A. YVWD hydrant setup on Chapman Heights Road
B. 4" fire hose elbow south of Chapman Heights Rd
C. 4" fire hose in culvert north of Chapman Heights Rd
D. Testing in progress (Day 1)
E. Testing in progress (Day 1)
F. Test in progress (from western bank) (Day 7)

Test Start		Jul-23-2018
Test End		Aug-06-2018
Basin Dimensions (L x W) (ft)		37 x 33
Average Water Height (ft)		2.5
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		974,084
Total Water Added (acre-feet)		3.0
Infiltration Rate (Constant-Head)	High (ft/d)	11.5
	Low (ft/d)	8.8
	Average (ft/d)	10.2
Infiltration Rate (Falling-Head)	High (ft/d)	9.5
	Low (ft/d)	7.25
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		5.1
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		2.5



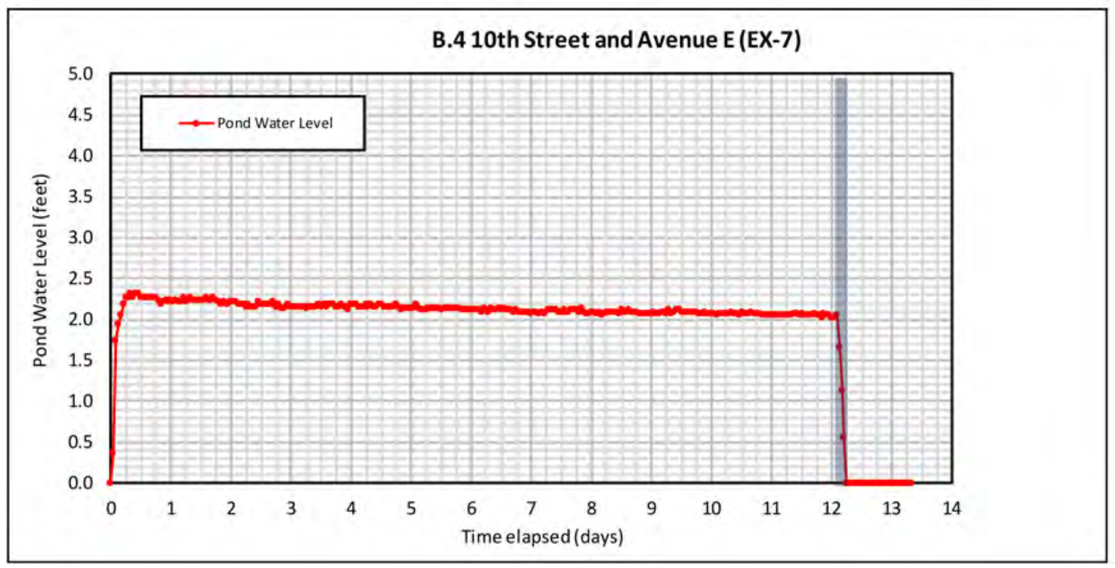
Conclusions:
- Results of infiltration testing indicate that the site is suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 5.1 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 2.5 feet/day. While long-term estimates consider expected clogging of the basin bottom from SWP water, actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.

Recommendations:
- Depending on size of a full-scale recharge project, pilot scale infiltration test is recommended to identify potential site vadose zone storage capacity constraints due to recharge mounding.
- Pilot testing combined with installation of monitoring wells north and south of the Western Heights Fault is recommended to confirm groundwater storage benefits from managed aquifer recharge at this location.

TODD GROUNDWATER

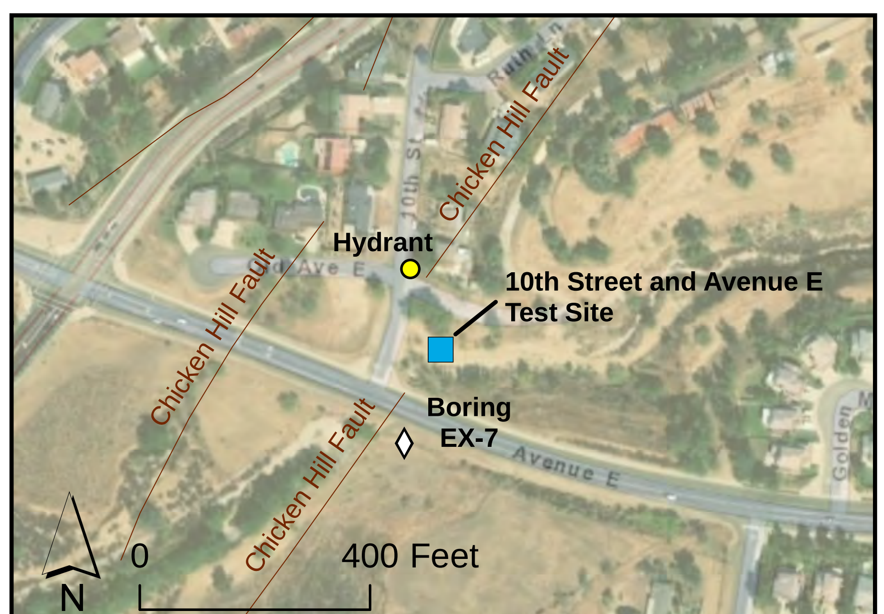
Figure 4
Chapman Heights Basin

Infiltration Test Results



A. Initial excavation of test infiltration basin
B. Setting up flow control skid
C. Temporary fencing and 4" fire hose from YVWD hydrant on 10th Street
D. Initial test basin filling (Day 1)
E. Testing in progress (Day 2)
Note abandoned pipes unearthed during excacation in background
F. Test in progress view from north (Day 2)

Test Start		Jul-30-2018
Test End		Aug-13-2018
Basin Dimensions (L x W) (ft)		39 x 36
Average Water Height (ft)		2.1
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		1,451,335
Total Water Added (acre-feet)		4.5
Infiltration Rate (Constant-Head)	High (ft/d)	13.44
	Low (ft/d)	12.04
	Average (ft/d)	12.7
Infiltration Rate (Falling-Head)	High (ft/d)	11.54
	Low (ft/d)	9.75
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		6.4
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		3.2



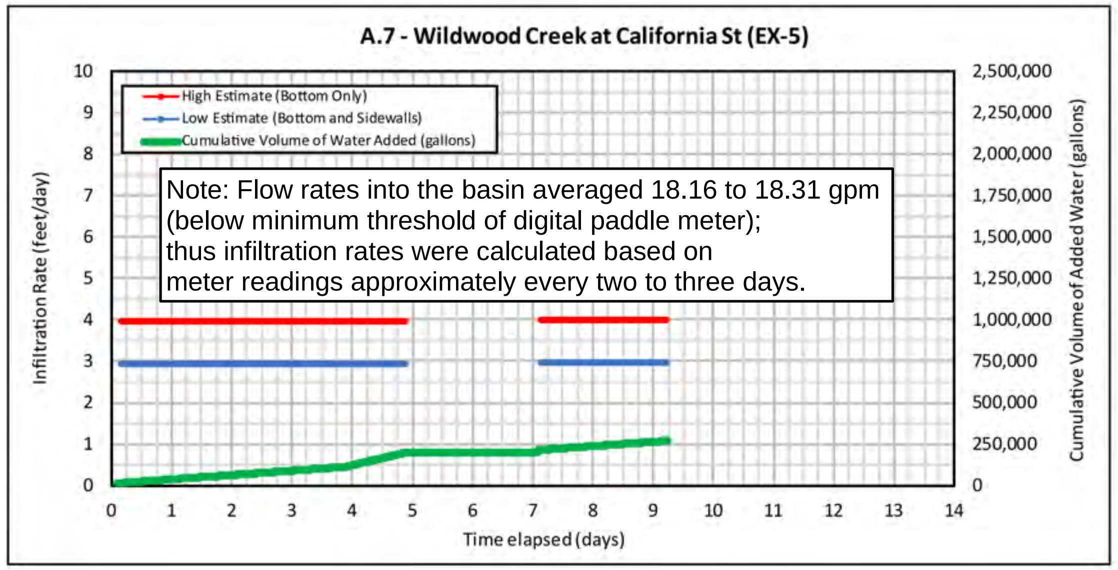
Conclusions:
- Results of infiltration testing indicate that the site is suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 6.4 feet/day.
- Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 3.2 feet/day.
- Relatively high infiltration rates are representative of the generally permeable vadose zone sediments (sand, gravel) encountered from 25 to 200 feet in adjacent exploratory boring EX-7 (located ostide of the channel south of Avenue E)
- Fine-grained silt/clay deposits encountered in the upper 25 feet of EX-7, were not encountered during excavation. It is possible that upper clay deposits are only located outside of the drainage channel.
- Depth to water in EX-7 was 115 ft-bgs in 2014, similar to water levels east of the fault, indicating that the Chicken Hill Fault is a partial barrier to subsurface flow at this location.
- Due to its downgradient location in the Calimesa Basin, The value of this site for recharge is contingent on potential benefits this site can provide to the Western Heights Subbasin.
- Water level differences of approximately 300 feet across the Chicken Hill Fault indicate the that the hydraulic connection between the site and Western Heights Subbasin is expected to be poor. However, further investigation and/or evaluation is needed to confirm this interpretation.

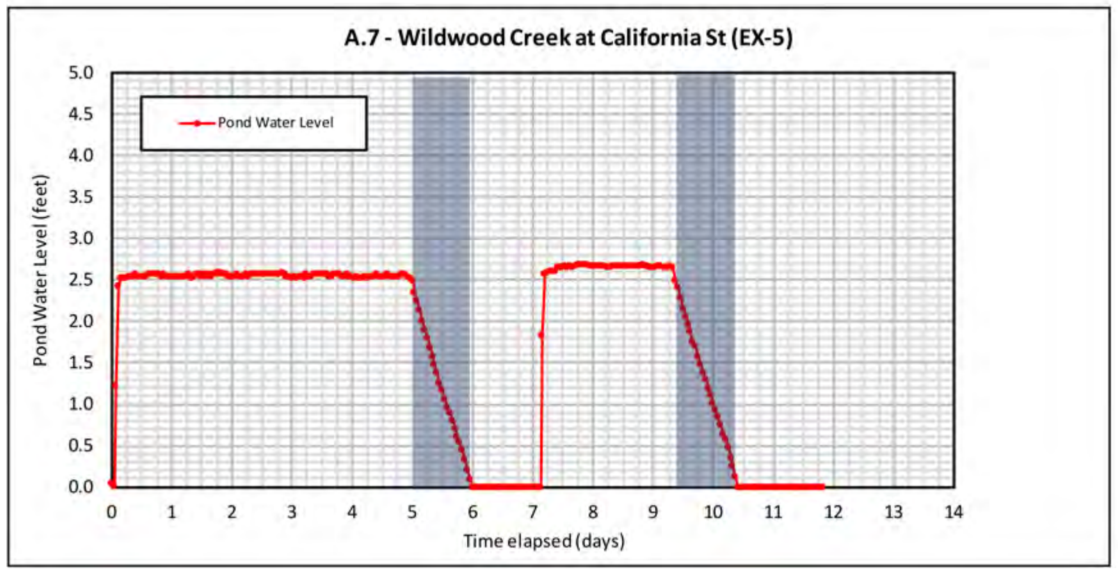
Recommendations:
- Pilot scale infiltration test with monitoring wells west/northwest of the Western Heights Fault would be needed to identify potential site vadose zone storage capacity constraints due to recharge mounding and to confirm if recharge can benefit the Western Heights Subbasin.

TODD GROUNDWATER

Figure 5
10th Street and Avenue E

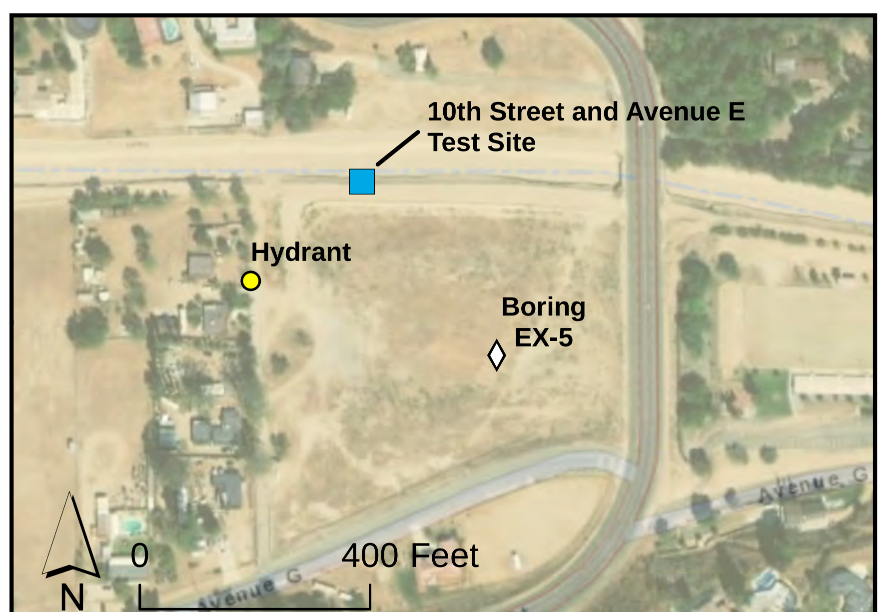
Infiltration Test Results





A. Initial excavation of test infiltration basin
B. Flow control skid and temporary fencing
C. Post-infiltration potholing to evaluate subsurface moisture conditions
D. Dry soil conditions below shallow silt layer occuring at 10-12 feet below the channel
E. Test in progress (Day 1)

Test Start		Aug-06-2018
Test End		Aug-20-2018
Basin Dimensions (L x W) (ft)		41 x 21
Average Water Height (ft)		2.5
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		270,060
Total Water Added (acre-feet)		0.8
Infiltration Rate (Constant-Head)	**High (ft/d)**	4
	Low (ft/d)	2.94
	Average (ft/d)	3.5
Infiltration Rate (Falling-Head)	**High (ft/d)**	3.07
	Low (ft/d)	2.4
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		1.7
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		0.9



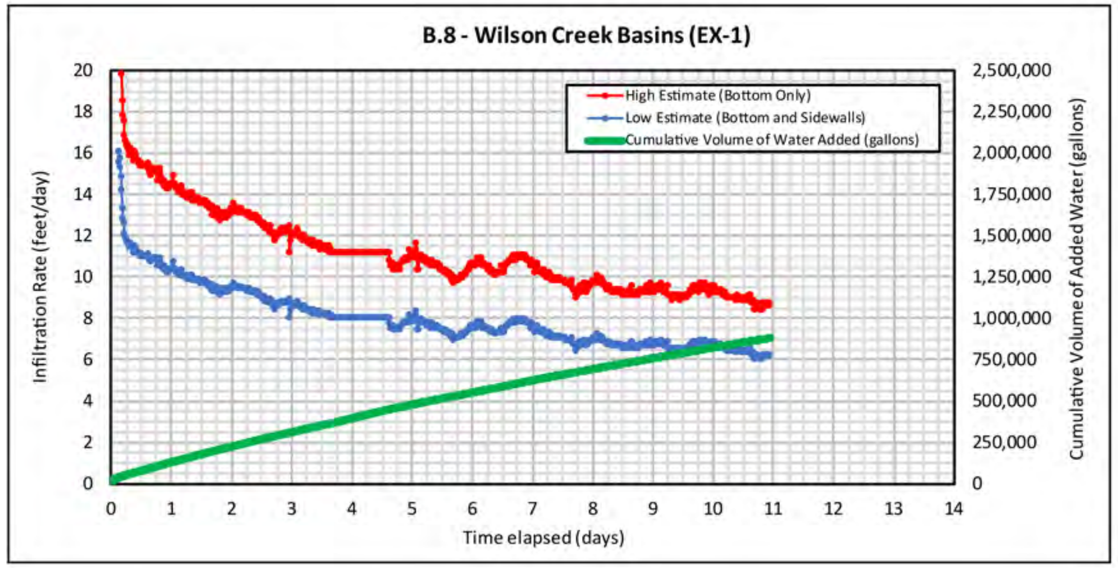
Conclusions:
- Results of infiltration testing indicate that the site (within the channel) is not suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 1.7 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 0.9 feet/day.
- Low infiltration rates appear to be due to low-permeability clayey silt layer, the top of which occurs at 10-12 feet depth. Dry soil conditions were observed below the clayey silt layer at end of testing.
- No fine-grained deposits were identified in EX-5 above 94 feet-bgs; fine-grained material appears to be associated with sediment load from natural stormflows.

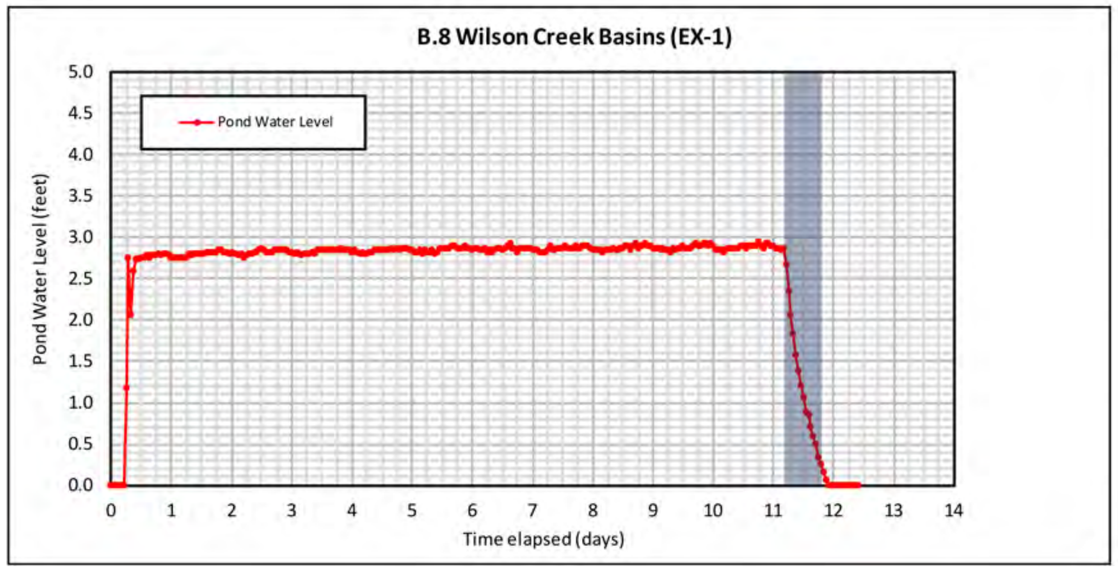
Recommendations:
- Near-surface coarse-grained sediments found in Wildwood Creek at California Street, appear to have limited thickness and are underlain by a fine-grained matrix associated with natural stormflows, which limit infiltration significantly.
- No additional actions are recommended at this site.

TODD GROUNDWATER

Figure 6
Wildwood Creek
at California Street

Infiltration Test Results





A. Initial excavation of test infiltration basin
B. 4" fire hose through intra-basin culvert
C. Clay on basin surface from historical SWP recharge operations; SWP water during test release from turnout
D. Fine-grained silt/clay 0-2.5 feet; silt/sand/gravel 2.5-5 feet)
E. Test in progress (Day 11)
F. Dry basin after falling-head test (Day 14)

Test Start		Aug-13-2018
Test End		Aug-27-2018
Basin Dimensions (L x W) (ft)		32 x 29
Average Water Height (ft)		3.0
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		882,120
Total Water Added (acre-feet)		2.7
Infiltration Rate (Constant-Head)	High (ft/d)	8.71
	Low (ft/d)	6.05
	Average (ft/d)	7.4
Infiltration Rate (Falling-Head)	High (ft/d)	7.39
	Low (ft/d)	5.51
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		3.7
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		1.8

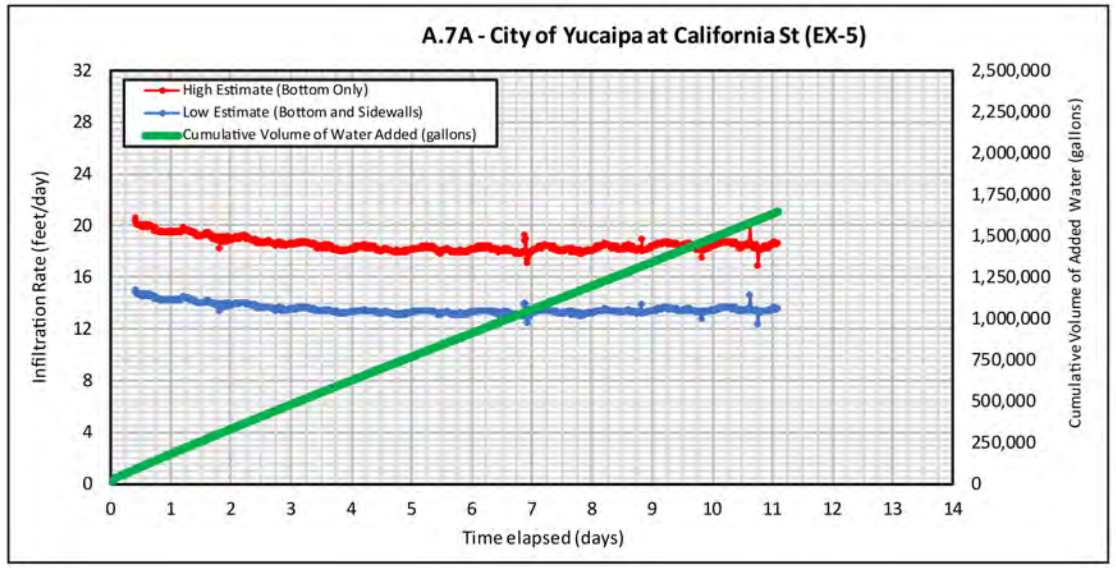
Conclusions:
- Results of infiltration testing confirm that the site is suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 3.7 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 1.8 feet/day.
- While long-term estimates consider expected clogging of the basin bottom from SWP water, actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.
- Declining infiltration rates during the test are associated with shallow recharge mounding identified by the USGS (Mooreland, 1970)

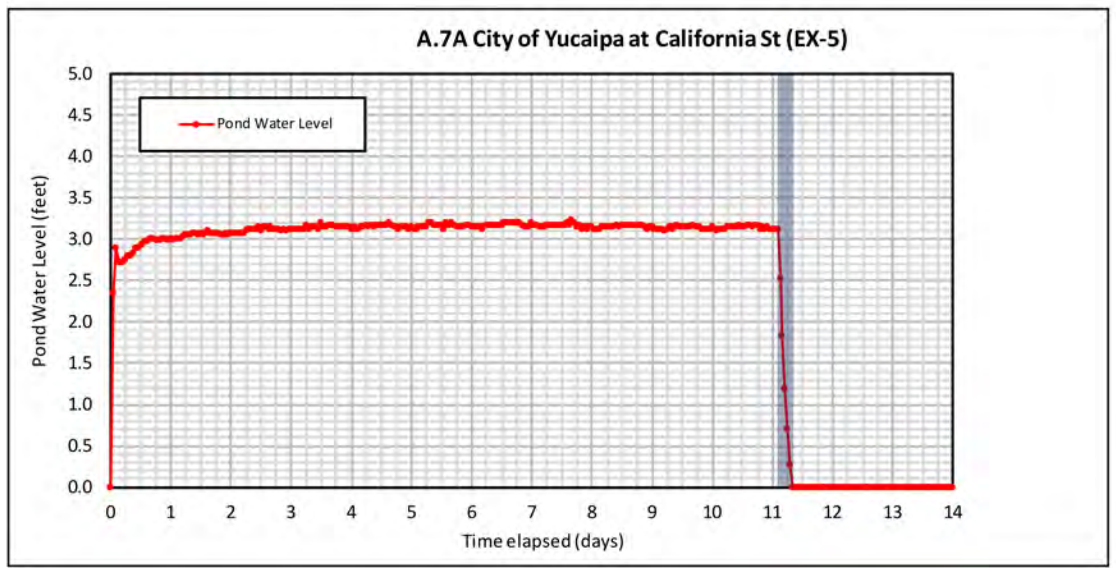
Recommendations:
- If site recharge goals are expected to exceed the operational capacity of the basins, the removal of the approximately upper 3 feet of sediment in each of the basins is recommended prior to future active recharge. Pilot-scale testing is not recommended at this site.

TODD GROUNDWATER

Figure 7
Wilson Creek Basins

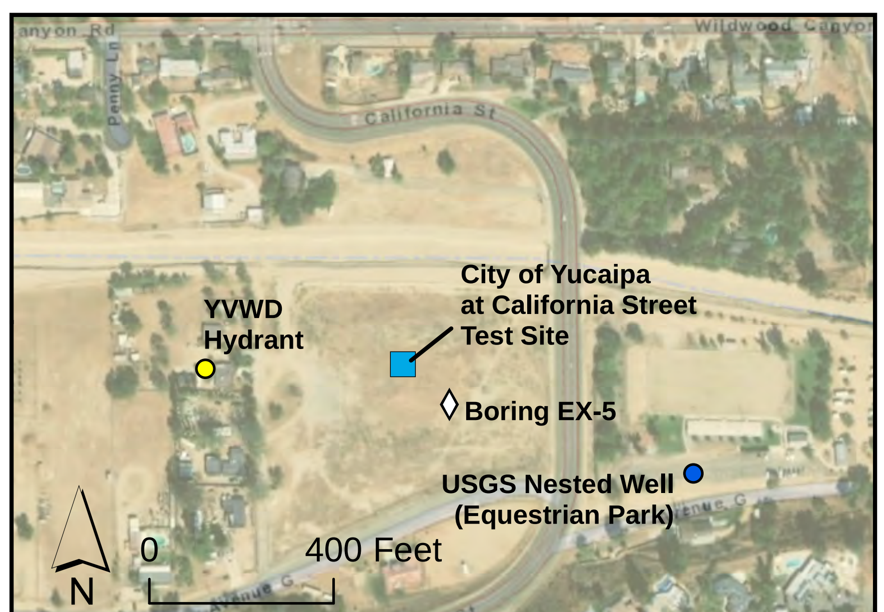
Infiltration Test Results





A. SMWC fire hydrant setup
B. 4" fire hose and traffic barricades
C. Post-excavation / flow control skid setup
D. Test in progress (Day 1)
E. Test in progress (Day 7)

Test Start		Aug-20-2018
Test End		Sep-03-2018
Basin Dimensions (L x W) (ft)		33 x 32
Average Water Height (ft)		3.0
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		1,646,180
Total Water Added (acre-feet)		5.1
Infiltration Rate (Constant-Head)	High (ft/d)	18.47
	Low (ft/d)	13.58
	Average (ft/d)	16.0
Infiltration Rate (Falling-Head)	High (ft/d)	16.82
	Low (ft/d)	14.5
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		8.0
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		4.0



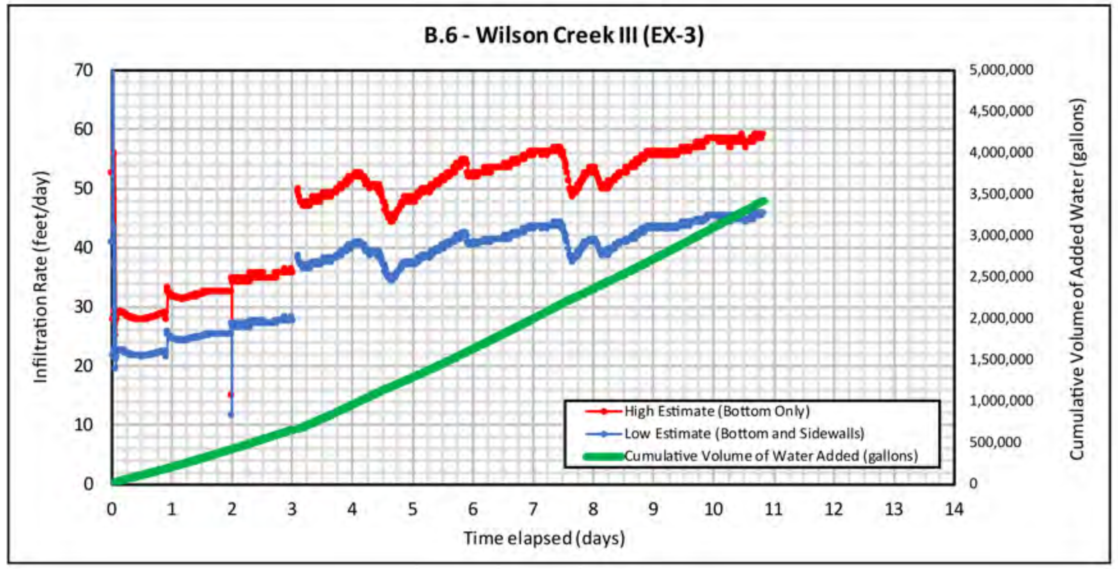
Conclusions:
- Results of infiltration testing confirm/indicate that the site is favorable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 8.0 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 4.0 feet/day.
- While long-term estimates consider expected clogging of the basin bottom from SWP water, actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.
- High infiltration rates are representative of almost exclusively coarse-grained deposits (sand/gravel) identified in EX-5.

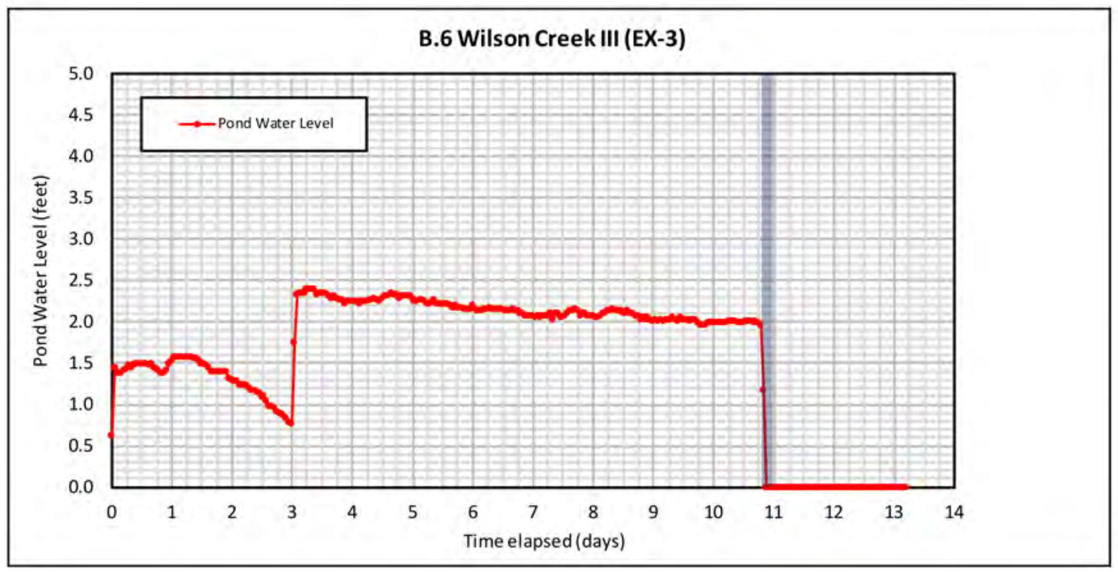
Recommendations:
- Pilot recharge testing is recommended to confirm full-scale basin infiltration rates and identify potential site vadose zone storage capacity constraints due to recharge mounding.

TODD GROUNDWATER

Figure 8
City of Yucaipa at California Street

Infiltration Test Results





A. YVWD fire hydrant setup
B. 4" fire hose along east side of 2nd St
C. Post-excavation / fencing
D. Test in progress (Day 1)
E. Test in progress (Day 4)

Test Start		Aug-27-2018
Test End		Sep-10-2018
Basin Dimensions (L x W) (ft)		45 x 20
Average Water Height (ft)		2.0
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		3,426,110
Total Water Added (acre-feet)		10.5
Infiltration Rate (Constant-Head)	High (ft/d)	59.18
	Low (ft/d)	44.8
	Average (ft/d)	52.0
Infiltration Rate (Falling-Head)	High (ft/d)	N/A; too fast
	Low (ft/d)	
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		26.0
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		13.0

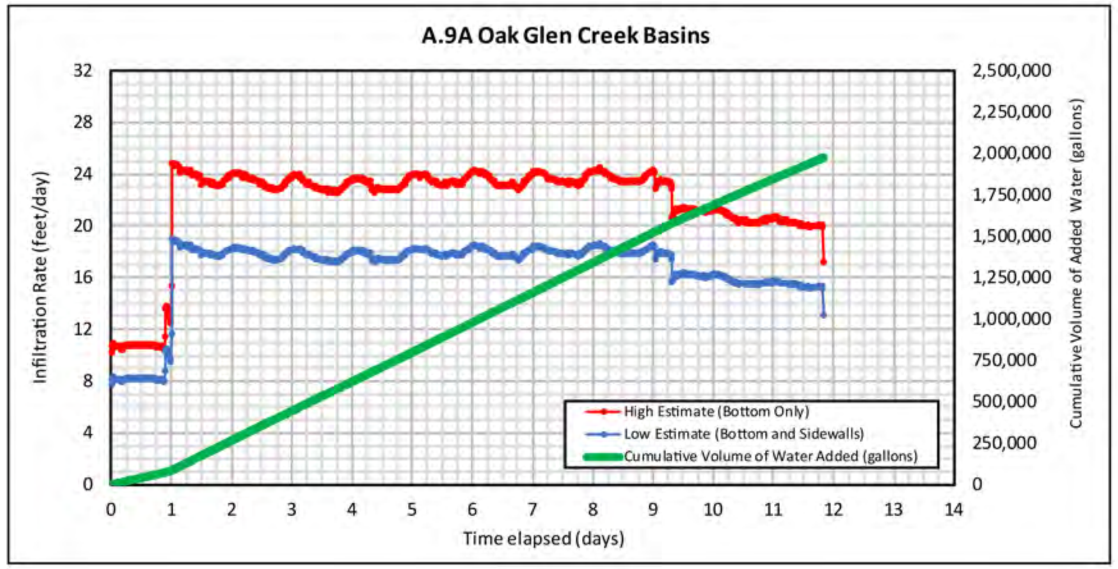
Conclusions:
- Results of infiltration testing confirm/indicate that the site is favorable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 26.0 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 13.0 feet/day.
- While long-term estimates consider expected clogging of the basin bottom from SWP water, actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.
- High infiltration rates are representative of almost exclusively coarse-grained deposits (sand/gravel) identified during excavating and in EX-3.
- High rates may also be partly attributable to the proximity of the test basin to a large-diameter conveyance pipe along the east side of 2nd St, presumably set in a gravel-filled trench.

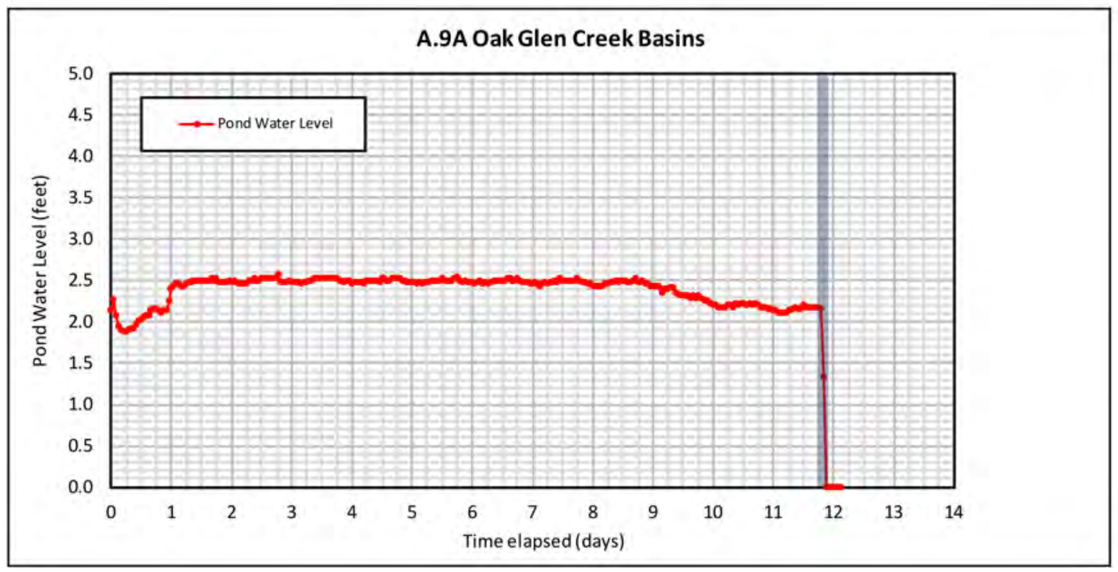
Recommendations:
- Depending on the size of the full-scale basin, pilot-scale infiltration testing is recommended to confirm full-scale initial infiltration rates and to identify potential site vadose zone storage capacity constraints due to recharge mounding. Installation of a monitoring well adjacent to the site is recommended to confirm the arrival and mounding effect of recharge water during pilot testing and to track future groundwater level changes.

TODD GROUNDWATER

Figure 9
Wilson Creek III

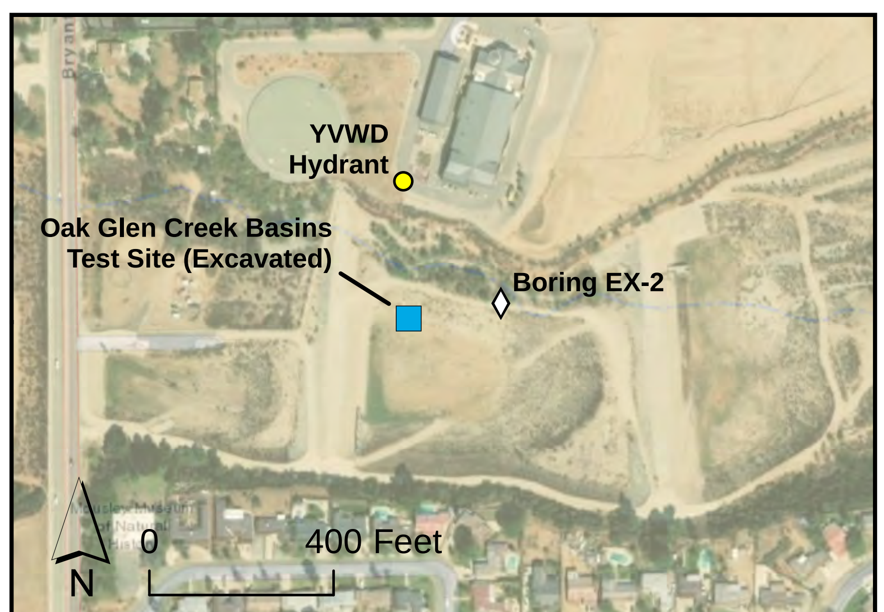
Infiltration Test Results





A. 4" fire hose / YVWD fire hydrant in background
B. Post-excavation / fencing setup (Day 1)
C. Test in progress (Day 3)
D. Test in progress (Day 4)
E. Post-testing - hard silt/clay layer shown in upper 3 feet

Test Start		Sep-03-2018
Test End		Sep-17-2018
Basin Dimensions (L x W) (ft)		32 x 32
Average Water Height (ft)		2.5
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		1,974,600
Total Water Added (acre-feet)		6.1
Infiltration Rate (Constant-Head)	High (ft/d)	24.06
	Low (ft/d)	17.86
	Average (ft/d)	21.0
Infiltration Rate (Falling-Head)	High (ft/d)	19.7
	Low (ft/d)	19.7
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		10.5
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		5.2



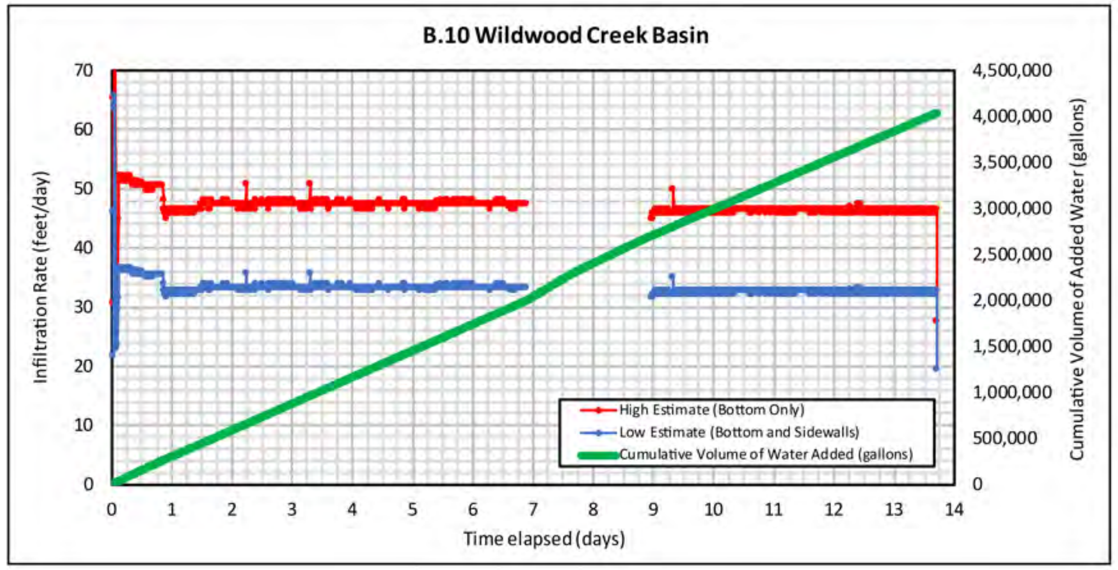
Conclusions:
- Results of infiltration testing confirm/indicate that the site is favorable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 10.5 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 5.2 feet/day.
- While long-term estimates consider expected clogging of the basin bottom from SWP water, actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.
- High infiltration rates are representative of almost exclusively coarse-grained deposits (sand/gravel/cobbles) identified during excavating and in EX-2.
- Infiltration test results for excavated and bermed test basins within Oak Glen Creek Basin highlight the importance removing the upper approximate 3 feet of fine silt/clay that has accumulated in the basin.

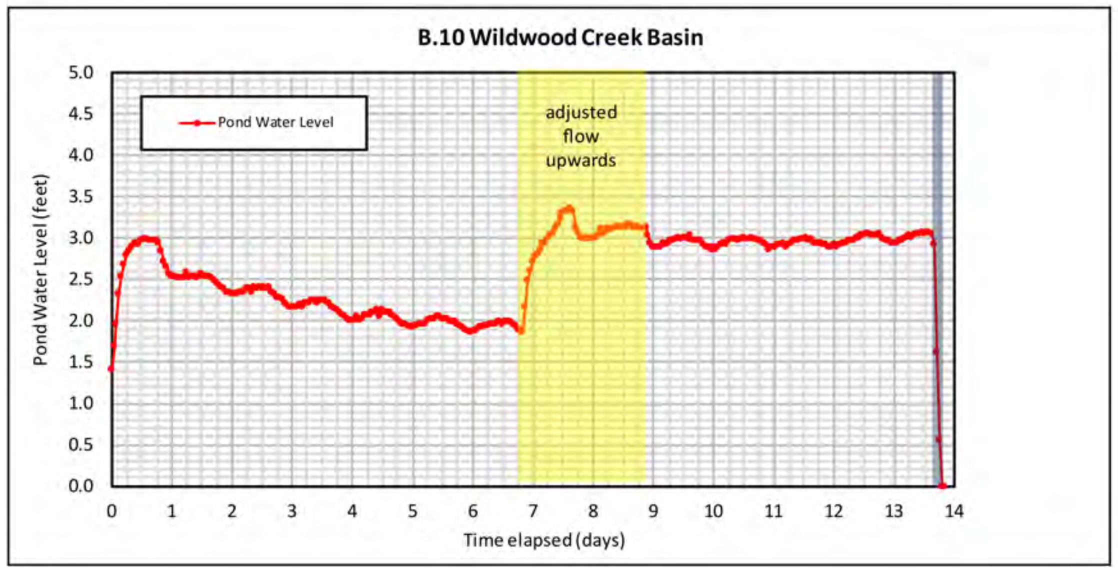
Recommendations:
- If site recharge goals are expected to exceed the operational capacity of the Oak Glen Creek Basins, the removal of the upper 3 feet of sediment in each of the Oak Glen Creek basins prior to future active recharge is recommended. Pilot-scale testing is not critical at this site.

TODD GROUNDWATER

Figure 10
Oak Glen Creek Basins (Excavated)

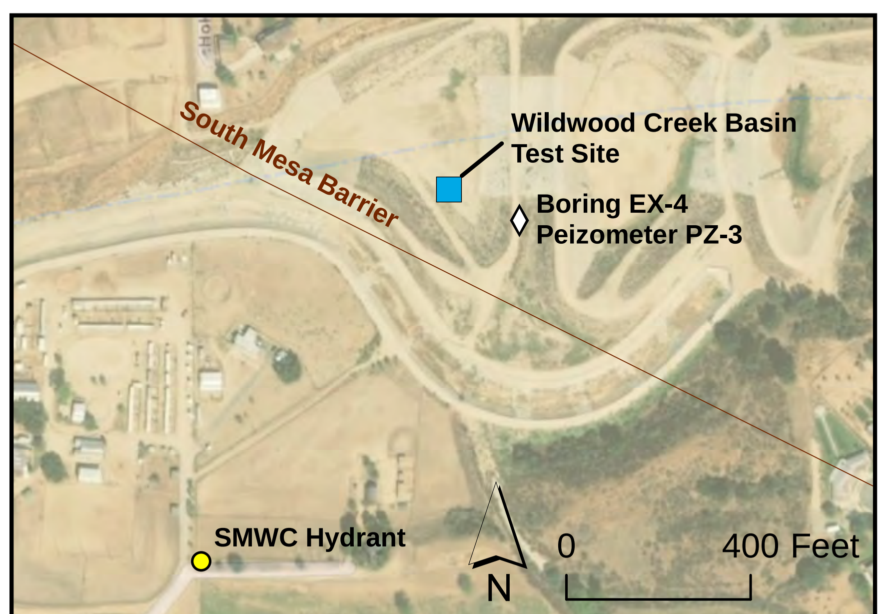
Infiltration Test Results





A. Traffic control and buried hose from SMWC hydrant
B. Testing in progress (Day 1)
C. EX-4 monitoring well (151' deep) located ~100' east of test basin
D. Flow control skid at end of test (Day 14)
E. Test in progress view from east (Day 7)

Test Start		Sep-10-2018
Test End		Sep-24-2018
Basin Dimensions (L x W) (ft)		29 x 28
Average Water Height (ft)		3.0
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		4,040,929
Total Water Added (acre-feet)		12.4
Infiltration Rate (Constant-Head)	High (ft/d)	45.8
	Low (ft/d)	32.2
	Average (ft/d)	39.0
Infiltration Rate (Falling-Head)	High (ft/d)	31.2
	Low (ft/d)	28.3
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		19.5
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		9.8



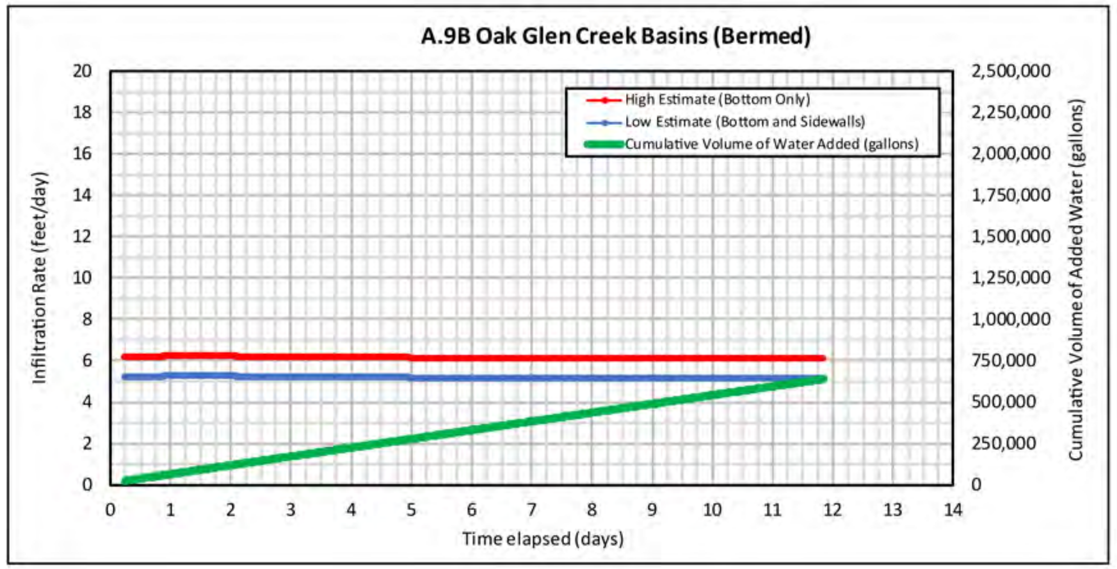
Conclusions:
- Results of infiltration testing indicate that the site is suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 19.5 feet/day.
- Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 9.8 feet/day.
- Relatively high infiltration rates are representative of the permeable vadose zone sediments (sand, gravel) encountered in adjacent exploratory boring EX-4
- No significant fine-grained silt/clay deposits were encountered in EX-4, which was drilled to 151 feet-bgs. Depth to water in MW-3 was 103 ft-bgs after 6 days of testing and rose to within 99 ft-bgs at the end of testing (after 14 days of infiltration).
- While long-term estimates consider expected clogging of the basin bottom from SWP water, actual long-term rates will be dependent on the specific site recharge goal and implementation of a basin maintenance plan.

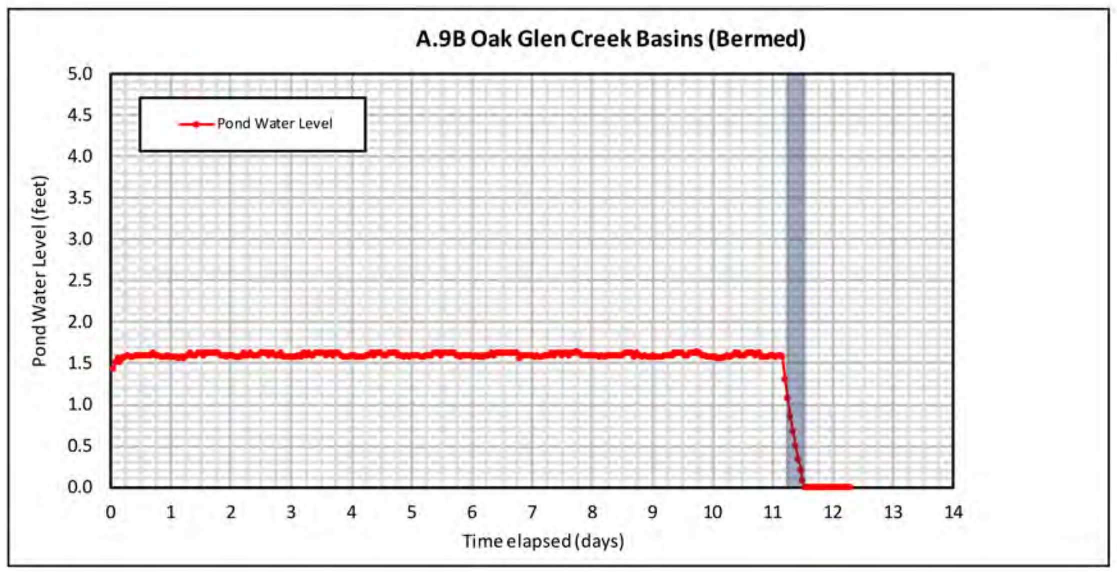
Recommendations:
- Pilot scale infiltration test is recommended to identify potential site vadose zone storage capacity constraints due to recharge mounding and the influence of the South Mesa Barrier.
- Prior to pilot testing, installation of monitoring well west of the South Mesa Barrier is recommended to confirm groundwater storage benefits from managed aquifer recharge at this location.

TODD GROUNDWATER

Figure 11
Wildwood Creek Basin

Infiltration Test Results

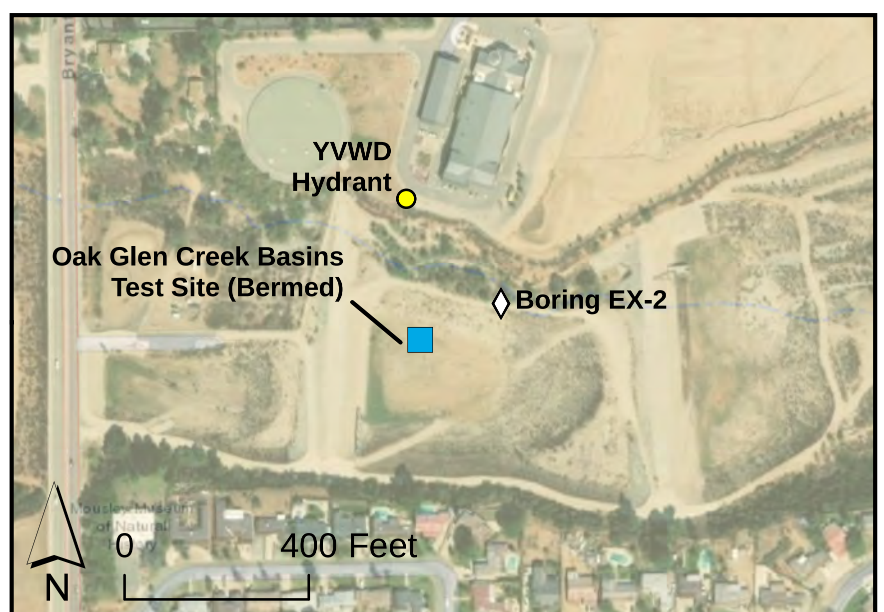




A. 4" fire hose / YVWD fire hydrant in background
B. Bermed (background) and Excavated Basin (foreground)
C. Fine silt/clay on ground surface
D. Post-excavtion and plastic sheeting bermed basin
E. Testing in progress (Day 1)
F. Leaked recharge water east of test basin (Day 6)

Test Start		Sep-17-2018
Test End		Oct-01-2018
Basin Dimensions (L x W) (ft)		34 x 34
Average Water Height (ft)		1.6
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		639,130
Total Water Added (acre-feet)		2.0
Infiltration Rate (Constant-Head)	High (ft/d)	6.12
	Low (ft/d)	5.15
	Average (ft/d)	5.6
Infiltration Rate (Falling-Head)	High (ft/d)	6.58
	Low (ft/d)	5.17
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		2.8
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		***2.8

*** Initial and long-term infiltration rates are the same, because the basin is already significantly clogged from lack of maintenance



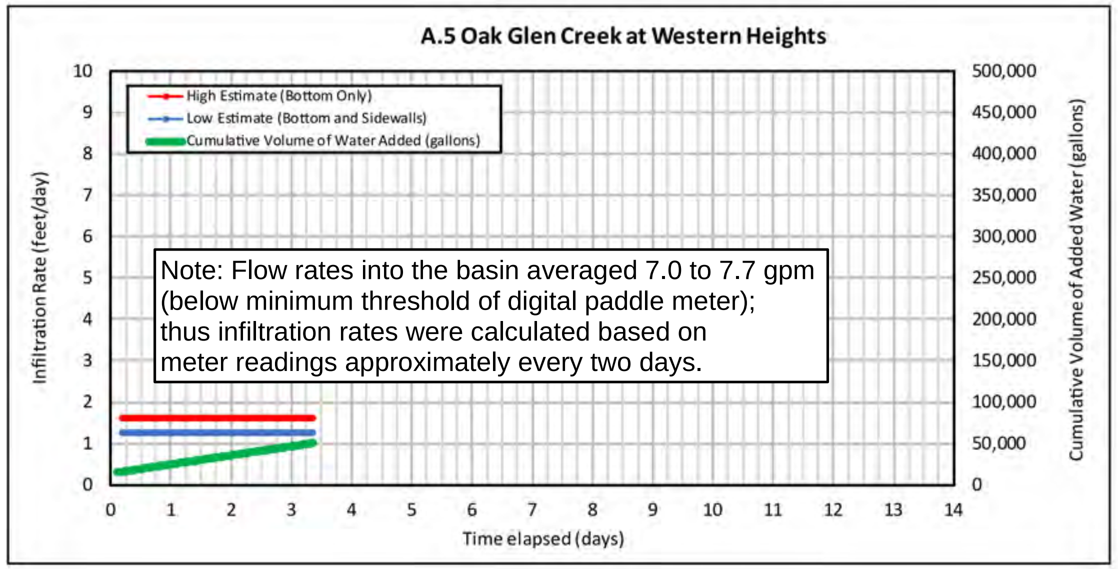
Conclusions:
- Results of infiltration testing of the bermed basin at Oak Glen Creek indicates that while the site is favorable for recharge, fine grained sediment in the upper approximately 3 feet of soil has decreased the recharge capacity of the basin significantly.
- Clean full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates of the excavated test basin) are estimated at 10.5 feet/day.
- Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 5.2 feet/day. Long-term rates assume a consistent basin maintenance and cleaning program.
- An estimated full-scale long-term infiltration rate of 2.8 feet/day is predicted, which is similar to infiltration rates (3.2 feet/day) measured during pilot testing in 2018.
(City of Yucaipa, Oak Glen Creek Recharge Report, 2018)

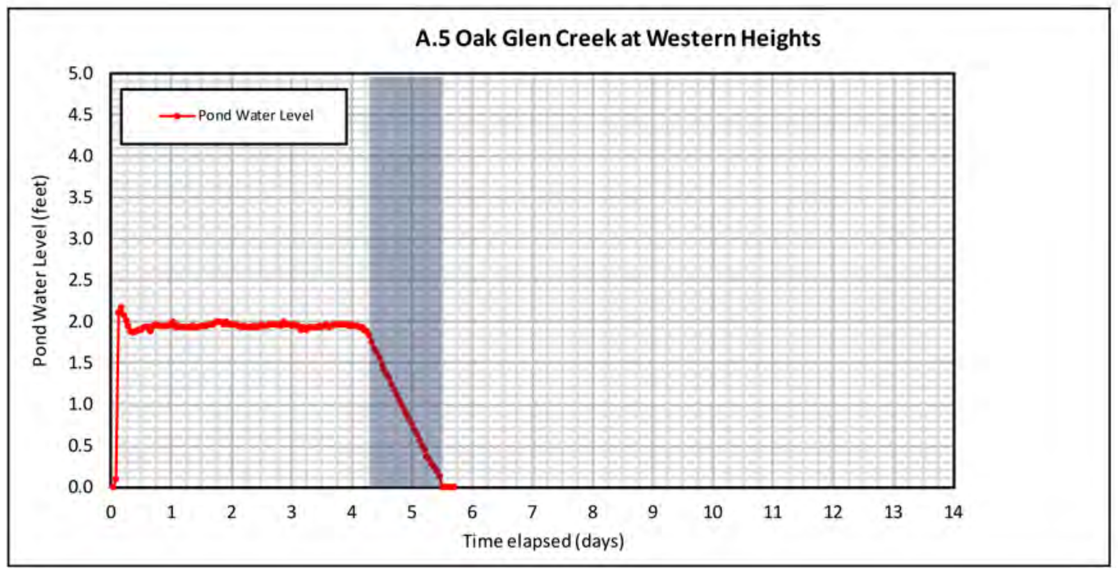
Recommendations:
- Infiltration test results for excavated and bermed test basins within Oak Glen Creek Basin highlight the effect that the upper 3 feet of accumulated fine silt/clay has on basin infiltration capacity.
- If site recharge goals are expected to exceed the operational capacity of the Oak Glen Creek Basins, the removal of the upper 3 feet of sediment in each of the Oak Glen Creek basins prior to future active recharge is recommended. Pilot-scale testing is not critical at this site.

TODD GROUNDWATER

Figure 12
Oak Glen Creek Basins (Bermed)

Infiltration Test Results





A. YVWD hydrant at 10th Street and 4" fire hose
B. 4" fire hose along northern channel bank west of 10th Street
C. Excavated basin, fencing, and soil stockpile
D. Initial test basin filling (Day 1)
E. Falling head test in progress view from south (Day 2)

Test Start		Sep-24-2018
Test End		Oct-01-2018
Basin Dimensions (L x W) (ft)		46 x 20
Average Water Height (ft)		2.0
Infiltrating Area Basin Bottom (ft^2)		960
Infiltrating Area Basin Bottom + Walls (ft^2)		1,270
Total Water Added (gallons)		50,632
Total Water Added (acre-feet)		0.2
Infiltration Rate (Constant-Head)	**High (ft/d)**	1.59
	Low (ft/d)	1.24
	Average (ft/d)	1.4
Infiltration Rate (Falling-Head)	**High (ft/d)**	1.64
	Low (ft/d)	1.45
Full-Scale Basin Est. Initial Infiltration Rate (ft/d)		0.7
Full-Scale Basin Est. Long-Term Infiltration Rate (ft/d)		0.4

Conclusions:
- Results of infiltration testing indicate that the site (within the channel) is not suitable for recharge.
- Full-scale basin initial infiltration rates (based on 50% of measured field-scale testing infiltration rates) are estimated at 0.7 feet/day. Long-term infiltration rates (based on 50% of full-scale basin initial infiltration rates) are estimated at 0.4 feet/day.
- Low infiltration rates appear to be due to low-permeability clayey silt sediments comprising the channel sidewalls and bottom.
- Fine-grained deposits were identified in EX-9 from 15 to 25 feet-bgs (approximately 0 to 10 feet below the channel bottom); however, fine-grained material also appears to be associated with sediment load from natural stormflows.

Recommendations:
- Surficial sediments found Oak Glen Creek at this location are comprised of predominately fine-grained sediments that may be naturally occurring and also associated with natural stormflows, which significantly inhibit infiltration.
- No additional actions are recommended at this site.

TODD GROUNDWATER

Figure 13
Oak Glen Creek at Western Heights

Appendix A

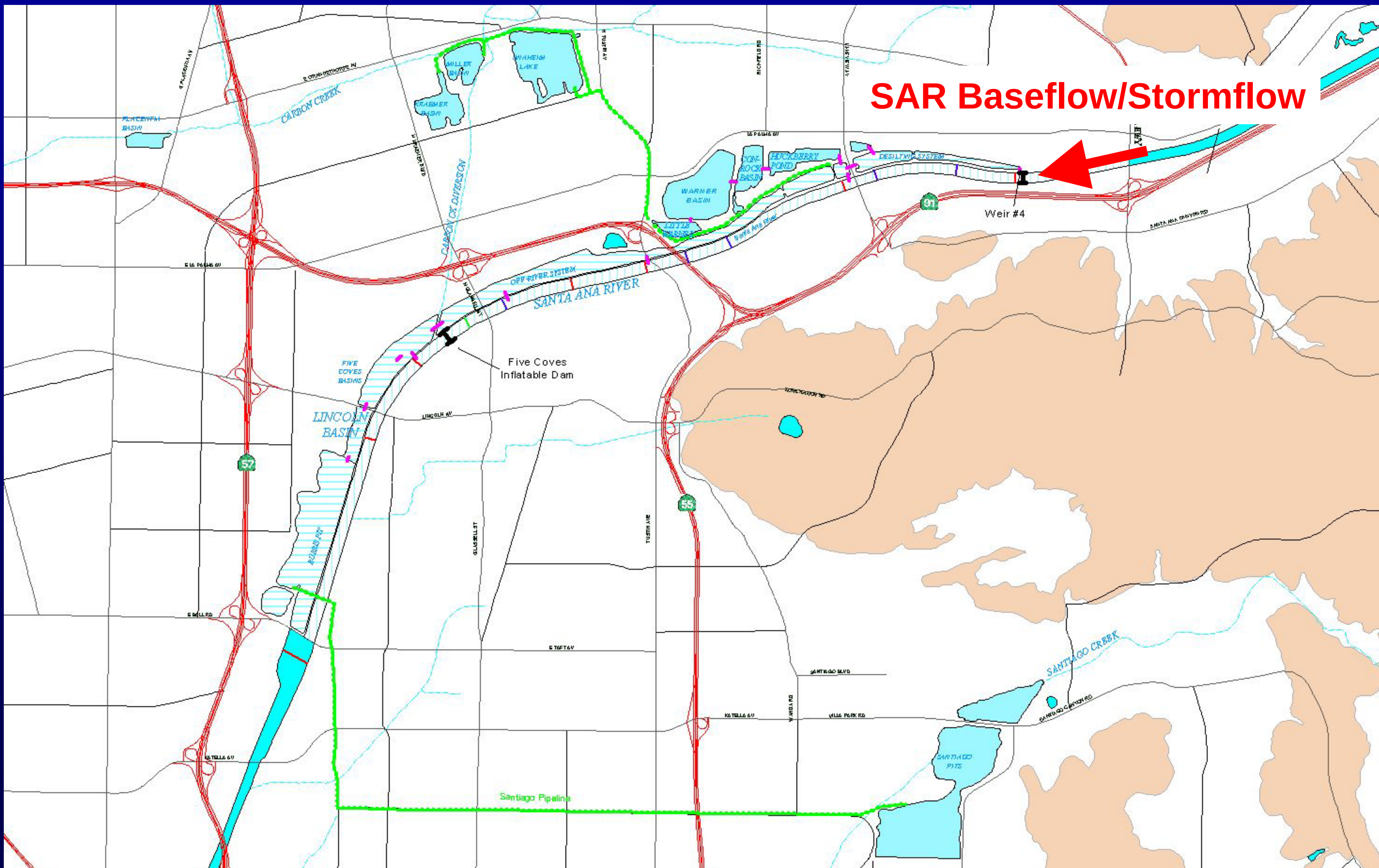
Phipps, D.W., Lyon, S., and Hutchinson, A. (2007) Development of a Percolation Model to Guide Future Optimization of Surface Water Recharge Basins. Presentation at 6th International Symposium of Managed Aquifer Recharge (ISMAR). October 30, 2007.

Development of a Percolation Model to Guide Future Optimization of Surface Water Recharge Basins

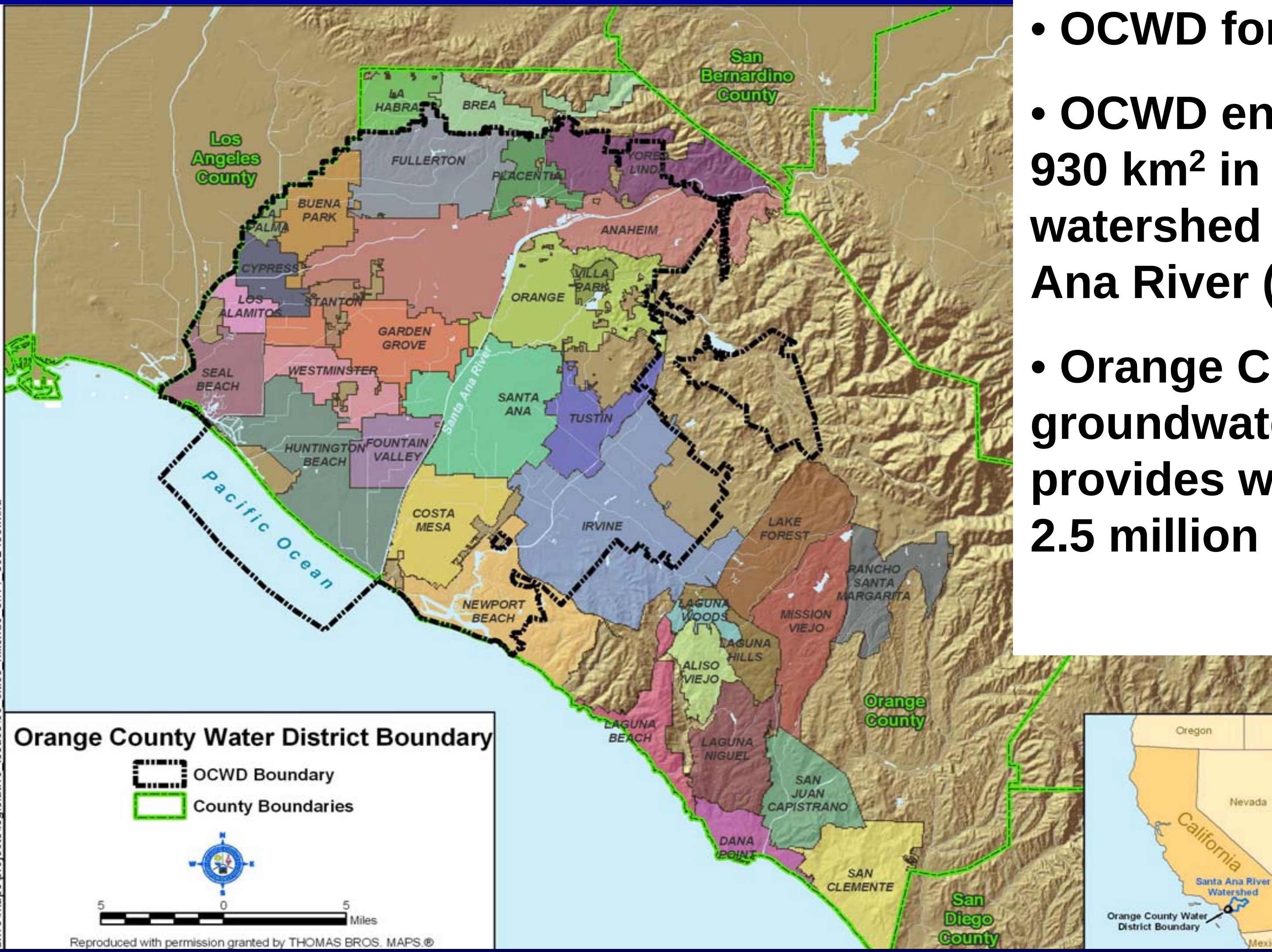
ISMAR 6
October 30, 2007

Donald W. Phipps, Jr.
Stephen Lyon
Adam Hutchinson

OCWD's 1,100 acres of MAR facilities receive imported and SAR water.



OCWD Background



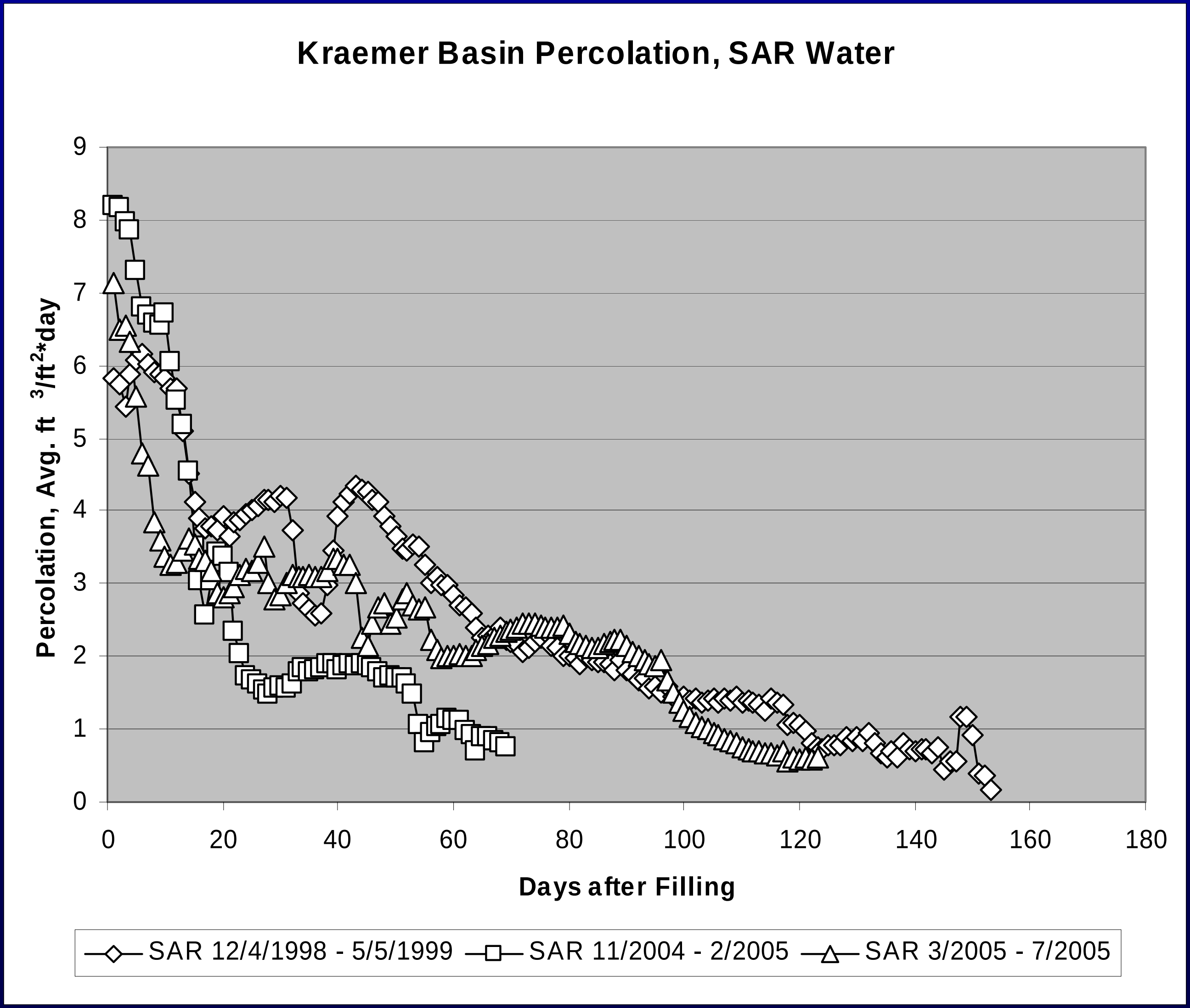
- OCWD formed in 1933
- OCWD encompasses 930 km^2 in the lower watershed of the Santa Ana River (SAR)
- Orange County groundwater basin provides water for over 2.5 million people

Primary Replenishment Source

- **250,000 AFY – Santa Ana River (52% of supply)**
- **500 cfs recharge rate and 51,000 AF of storage**
- ***1,600 acres of recharge basins***

Problem: Suspended Solids Deposited on Basin Bottoms During Percolation Form a Fouling Layer

Fouling Layer Accumulation Leads to Percolation Rate Decay



Percolation decline observed in Kraemer Basin during percolation of Santa Ana River (SAR) water

From Percolation Studies at OCWD (1987-1990)…

- Percolation reduction appeared primarily a function of fine suspended solids accumulation
- Accumulation at or very close to the sediment/water interface responsible for loss of percolation
- Percolation loss appears to follow a log decay relationship

Objective: To Model OCWD Recharge Basin Percolation Kinetics

A Basin Percolation Kinetic model will:

- Provide an insight regarding mechanisms responsible for observed percolation rate decay kinetics.

- Assist in predicting recharge basin water production.

- Define parameters that may be manipulated to improve recharge basin percolation performance.

Model Hypotheses

Percolation decay:

- Is caused by accumulation of fine material deposited by percolation water flux at the sediment/water interface
- Is related to accumulation of foulant material by a log decay function

Hypothesized Relationship Between Foulant Accumulation and Percolation

$$Q = Q_o * e^{-rL}$$

Where:

Q **= Observed percolation rate at L (ft^3/ft^2 per day)**

Q_o**= Initial percolation rate @ L=0 (ft^3/ft^2 per day)**

r **= Sediment/Foulant Interaction Coefficient (ft^2/mg)**

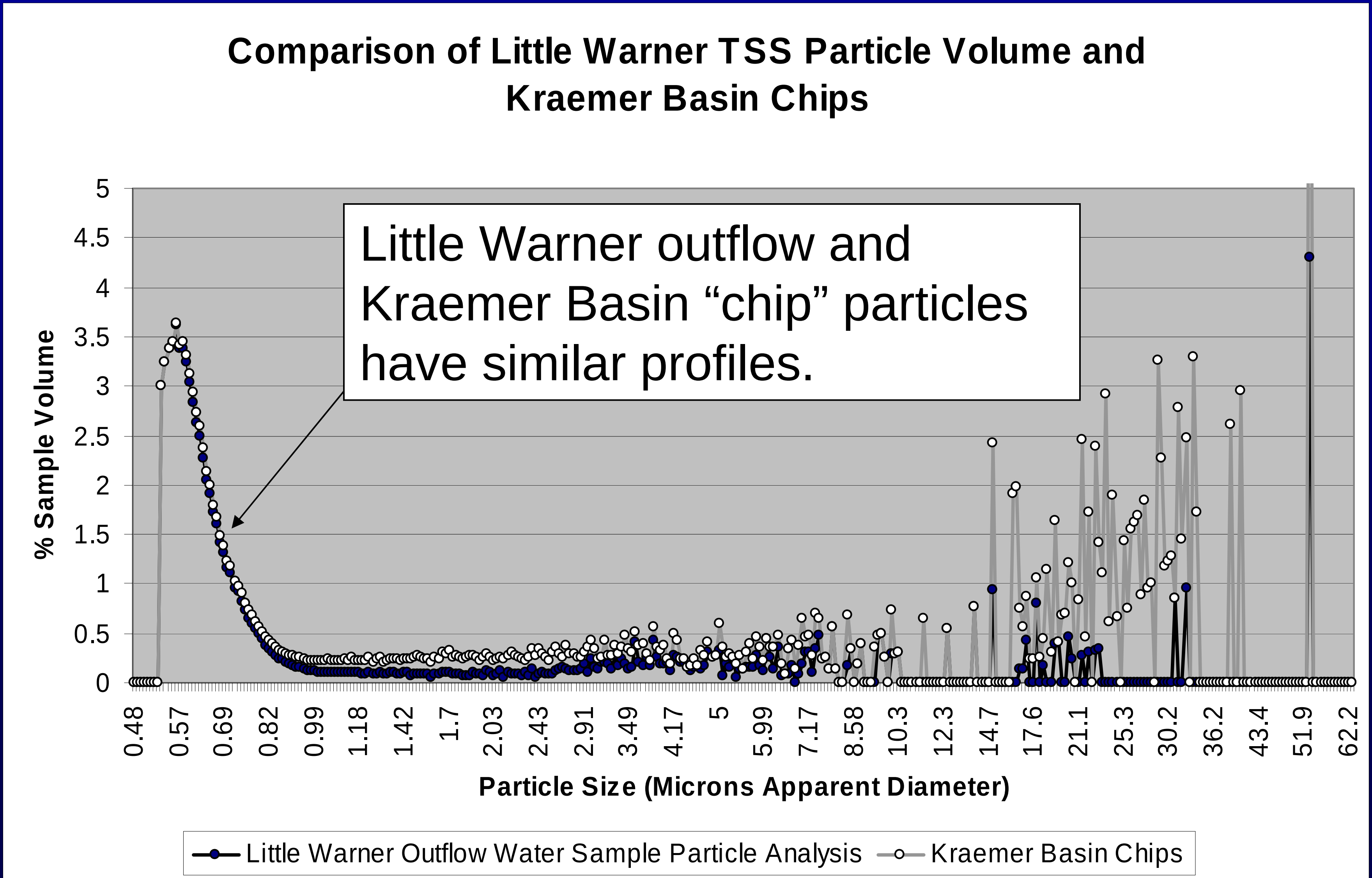
L **= Total mass of solids on the bottom (mg/ft^2)**

- **Advantage –** ***terms in model all defined by measurable field parameters***

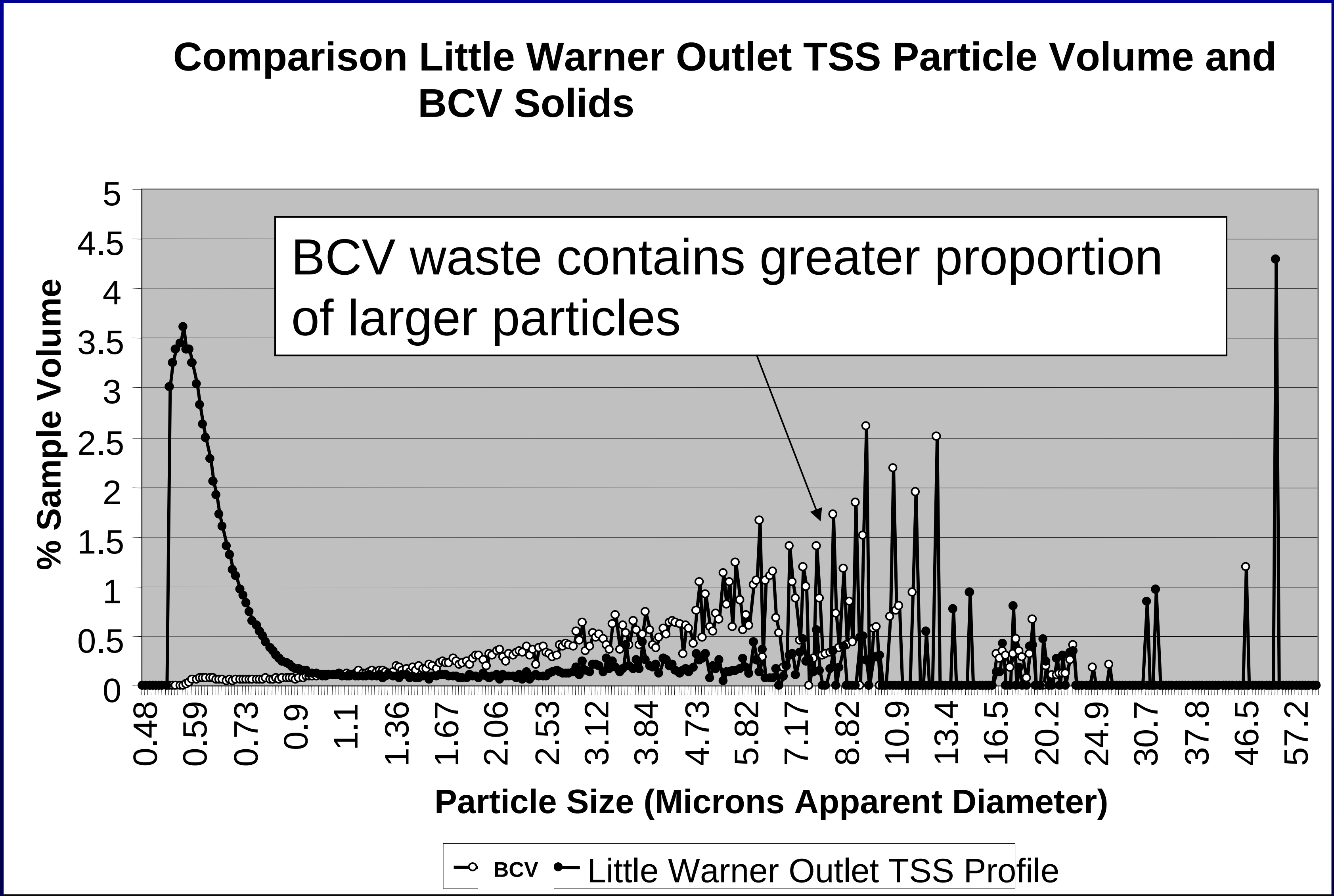
TSS for Laboratory Tests Obtained from “Chips” of Accumulated Fines

- Clay chips collected from the bottom of Kraemer Basin were mixed with bank-filtered SAR water to create TSS concentrations ranging from 20 to 400 mg/L. Other material was obtained from OCWD Basin Cleaning Vehicle (BCV) effluent.

Foulant Particle Size Distribution Comparison



Little Warner TSS vs. BCV Effluent Material

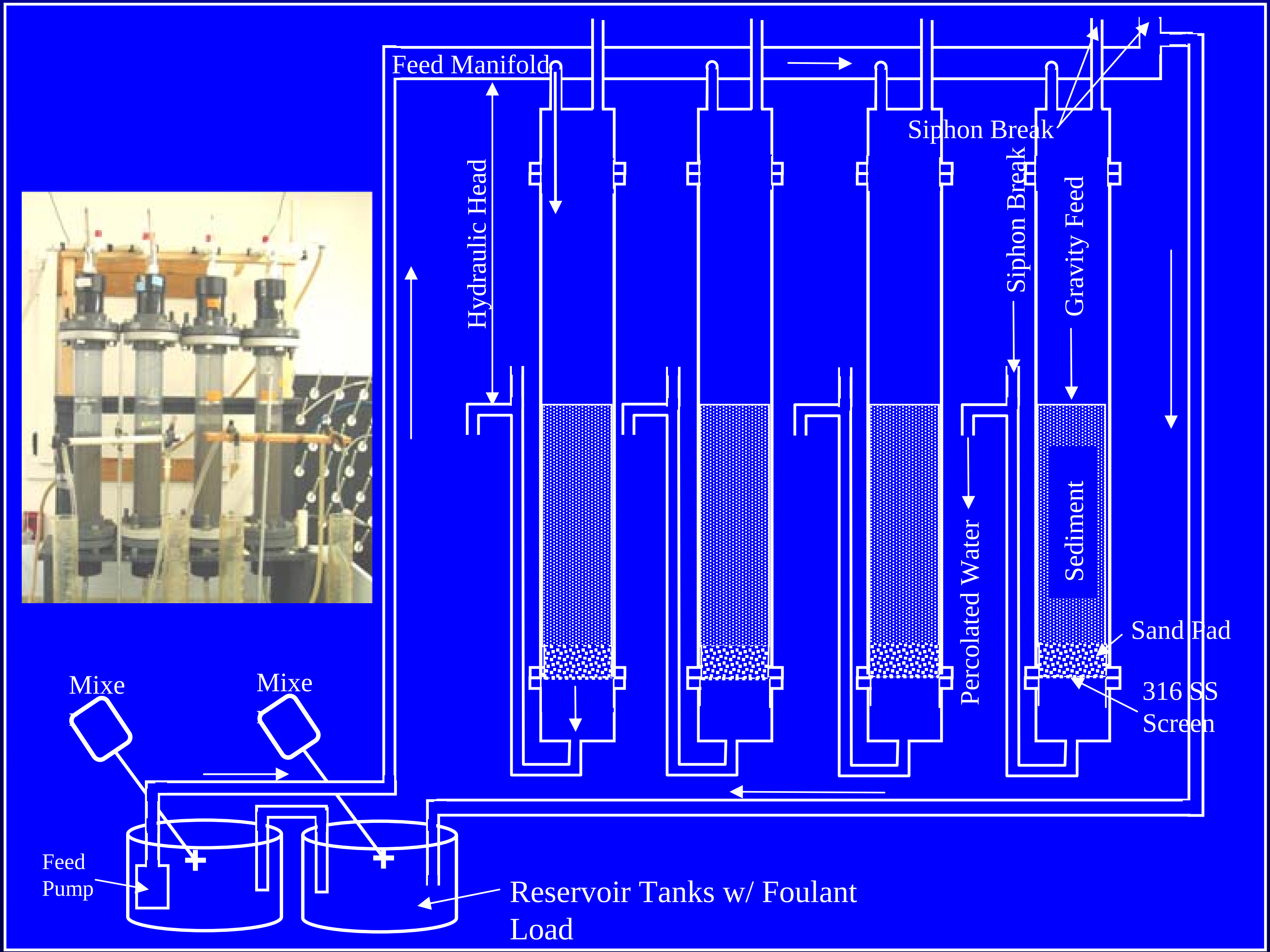


Model Hypothesis Tested Using 3” PVC Columns

Laboratory Test System:

Kraemer Basin sediment loaded onto 3” clear PVC columns operated at constant head pressure with SAR water containing a defined TSS load

Laboratory Test Column Schematic



Determination of r Value for Laboratory Columns

Obtain flow (ml/min) at intervals from 3” columns percolating well-derived SAR water containing KB chip fines at a desired TSS load (mg/L)

↓

Determine instantaneous percolation rate (ft^3/ft^2*day) using flow data and column geometry

↓

Determine total water percolated (ft^3) and solids deposited in column (mg/ft^2) as a function of time by calculating the total water percolated at each time point and multiplying by solids load (mg/ft^2)

→

Plot total solids deposited, mg/ft^2 (L) vs. observed column percolation (ft^3/ft^2*day, Q)

↓

Use nonlinear regression techniques to fit data to a log decay relationship:

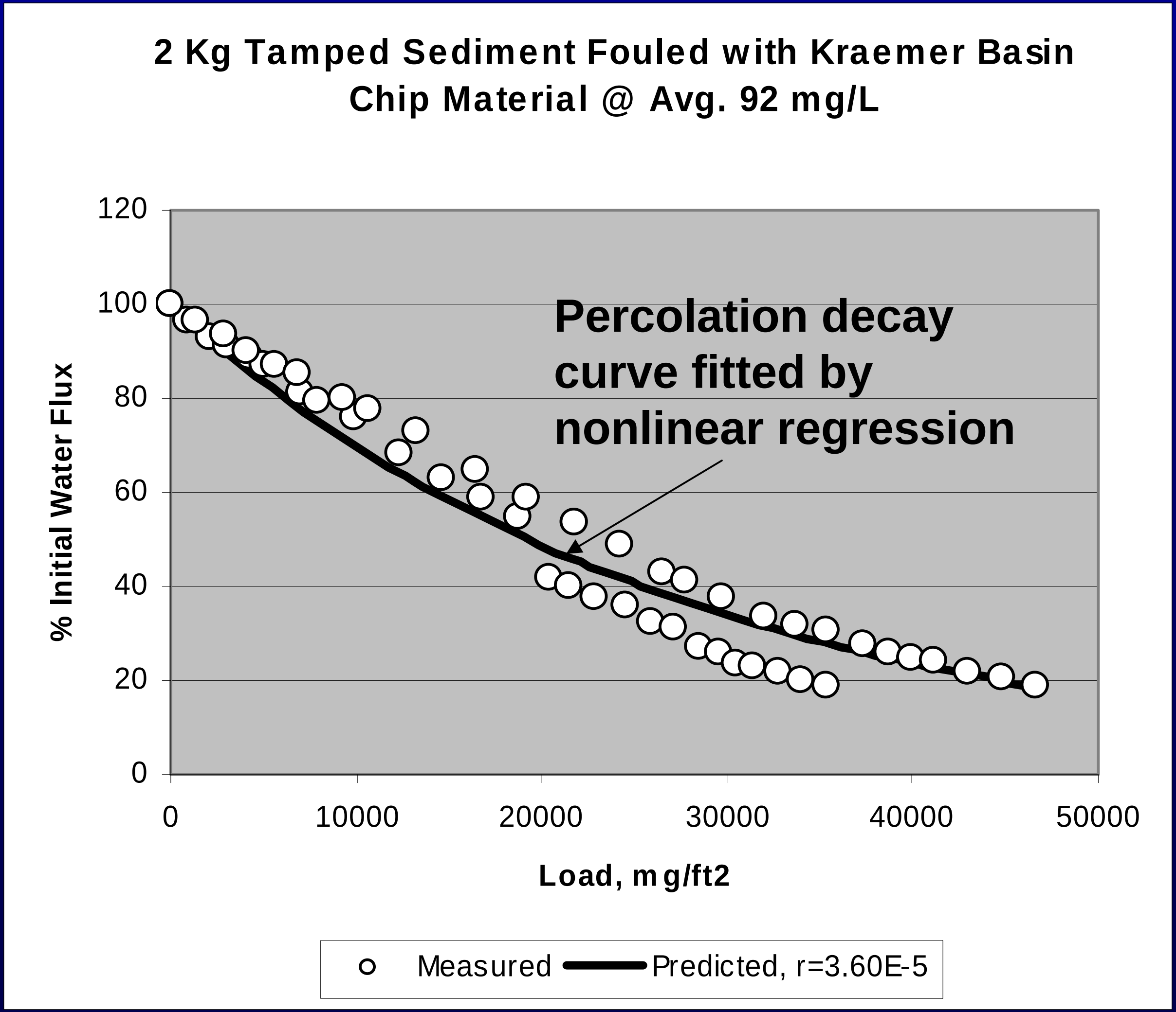
$$Q = Q_o*(e^{(-r*\text{solids loaded, mg/ft2})})$$

Determine averaged value for r from replicated columns

↓

To predict percolation kinetics, use laboratory-derived value for r and integrate L over 0.1 day increments (using given TSS values) to express percolation vs. time

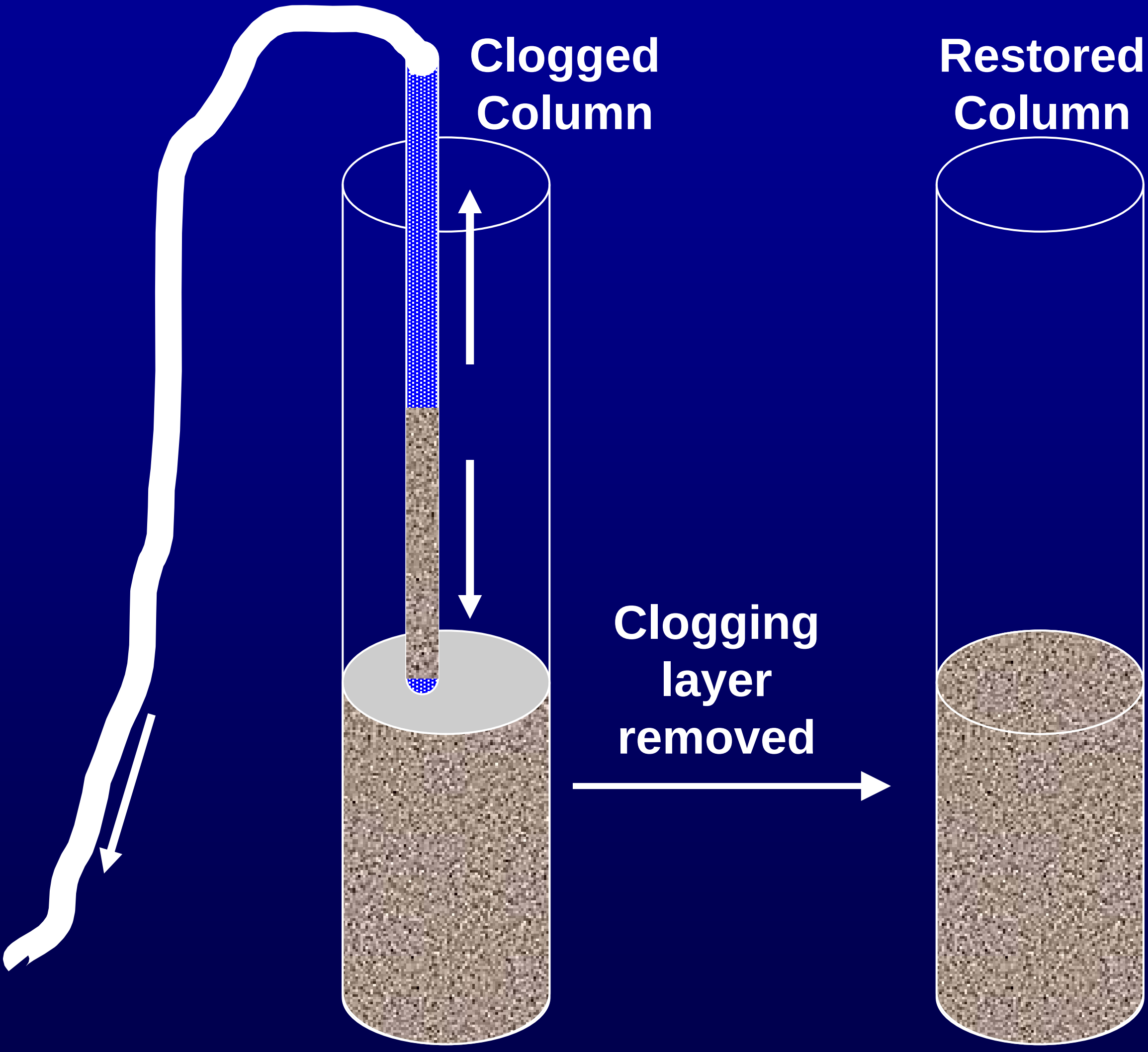
Model Fitted to Test Column Data



The model was fitted to test column data by manipulating the sediment/foulant interaction coefficient (r) with method of Marquardt nonlinear regression.

In most cases, the model explained <90% of the data variability.

Fouled Column Q Restored by Removing Top Layer of Sediment



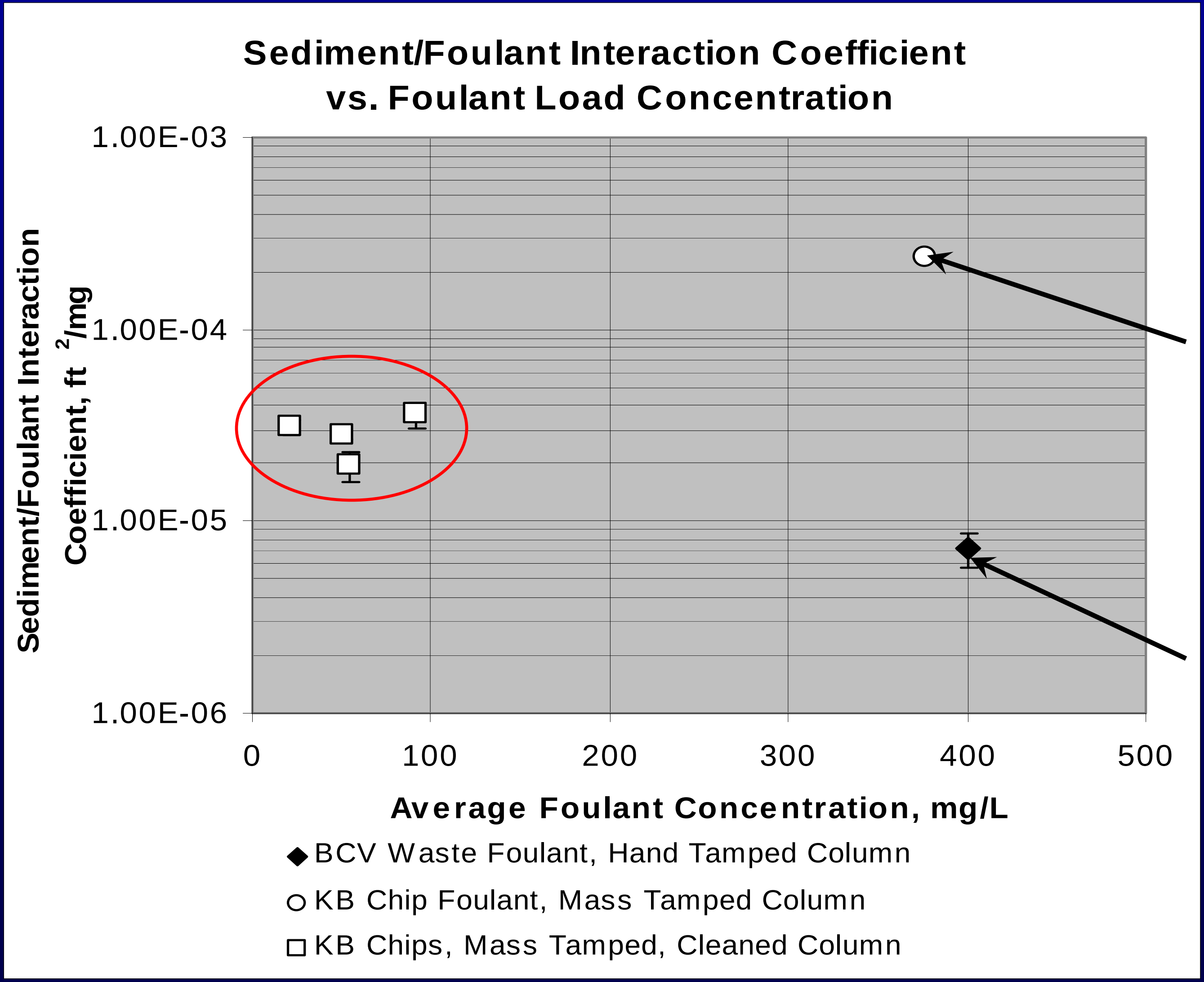
Restoration of percolation by aspiration of accumulated fines from upper 1cm of column *consistent with hypothesis that percolation reduction caused by foulant accumulation at the soil/water interface*

Multiple Column Tests were Performed at Different Foulant Loading Rates

- Columns loaded at various TSS concentrations ranging from 21 to 377 mg/L

- SAR baseflow: Avg. 23 mg/L
- SAR stormflow: Avg. 400 mg/L

Sediment/foulant interaction coefficient (r) is nearly constant for TSS <100 mg/L.

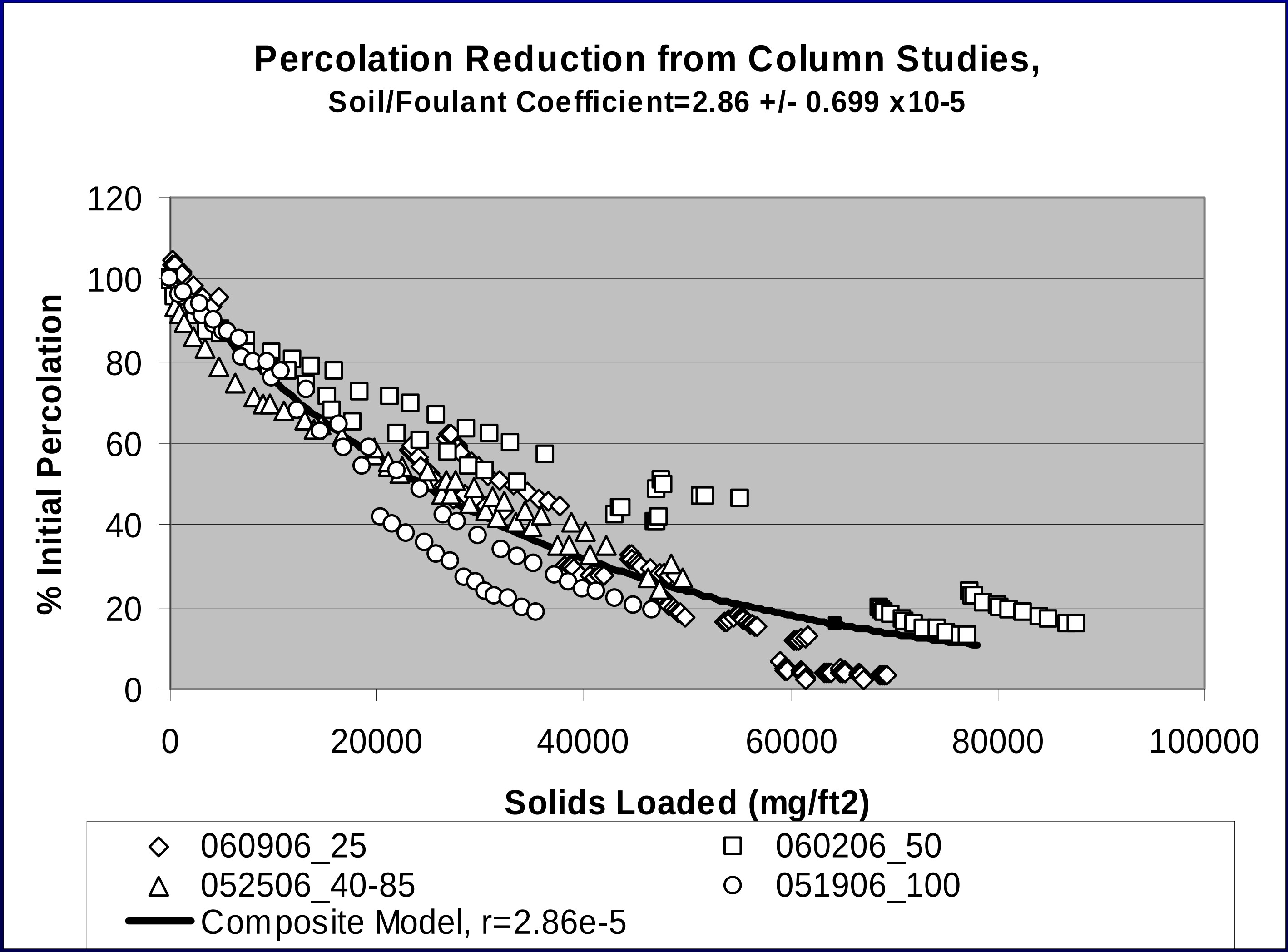


Kraemer Basin (KB) foulant material r values vary only slightly below 100 mg/L load.

At greater loading rates, KB fines foul more (greater r). Greater compaction possible?

r depends on foulant: BCV waste, with a greater average particle size than KB material exhibits lower r (fouls less)

Deriving Sediment/Foulant Interaction Coefficient (r) From Statistically Similar Column Data



Nonlinear regression of combined data from column experiments where foulant loading was <100 mg/L allowed calculation of an aggregate r value for Kraemer Basin Chip material:

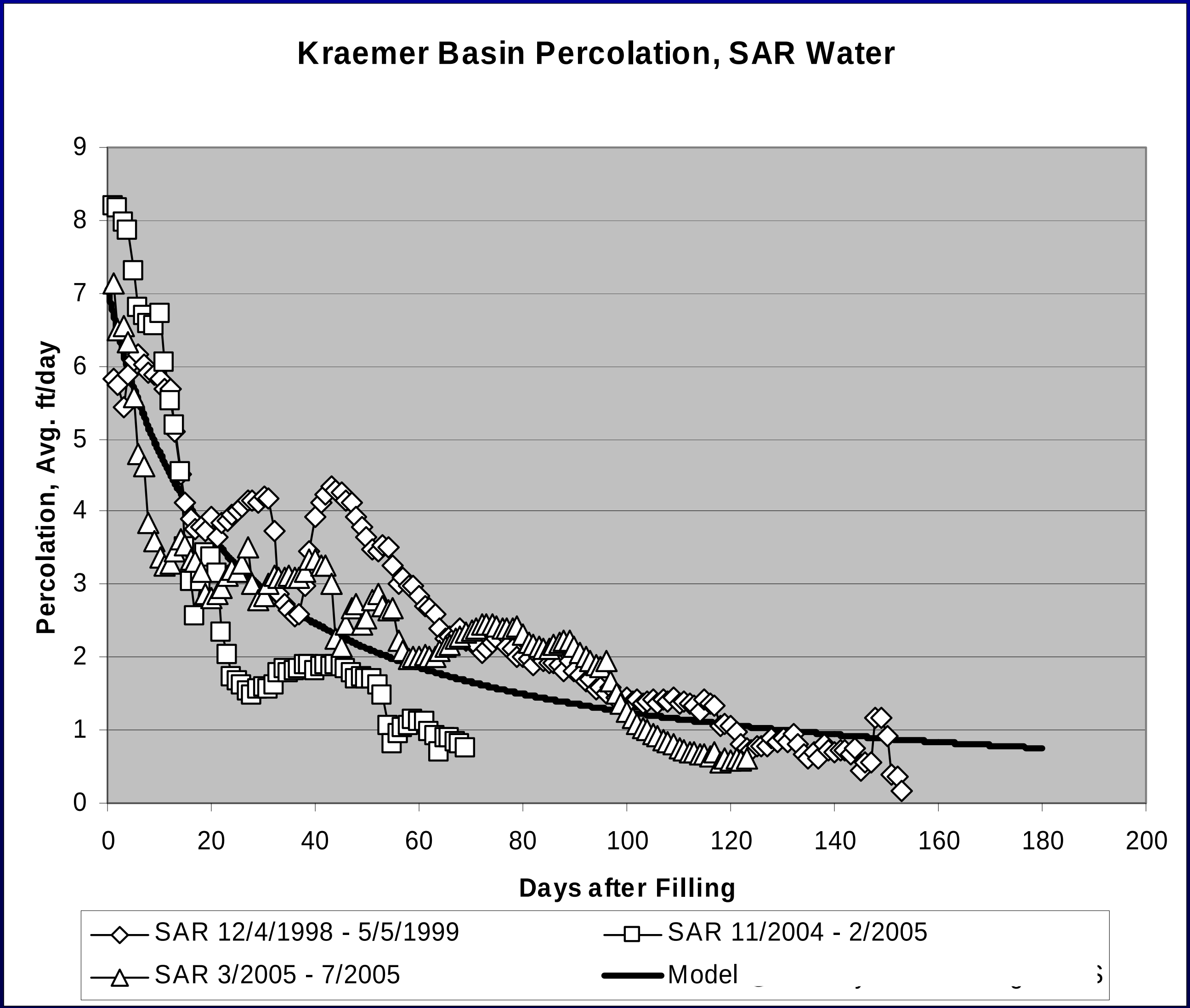
r= 2.86+/-0.7 x 10^{-5} ft^2/mg

(2.66x10^{-6} m^2/mg)

Some Factors That May Affect the Sediment/Foulant Interaction Coefficient (r):

- Foulant particle size distribution
- Soil particle size distribution
- Foulant geochemical composition
- Presence of materials increasing foulant adhesion (e.g., biopolymers)
- Deposition rate (slow vs rapid)

Describing SAR Water Percolation Decay Kinetics in Kraemer Basin Using Laboratory Column-Derived Value of r.



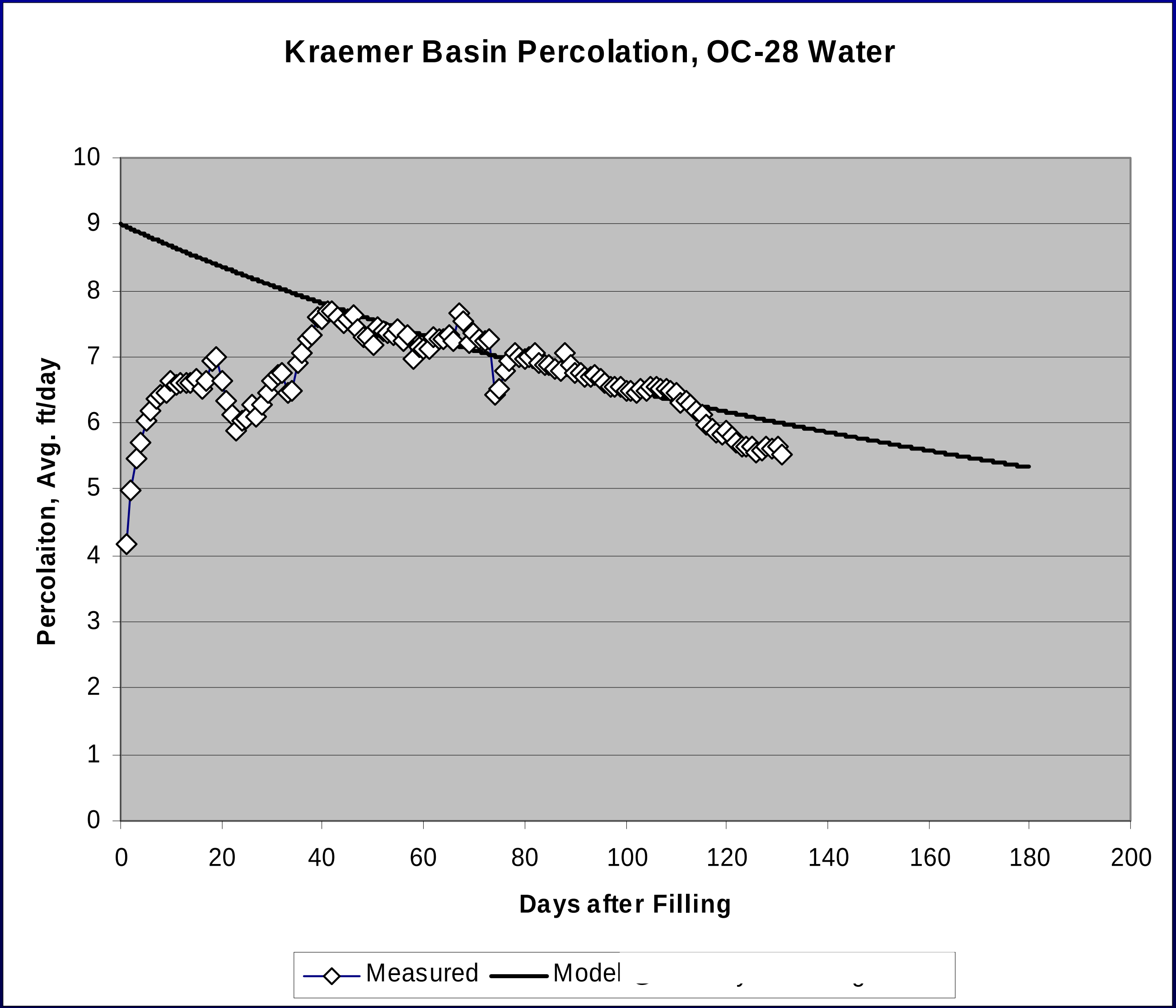
Model:

Q_o=7.05 ft^3/ft^2*day ($2.03 m^3/m^2$*day)

r=2.86×10^{-5} ft^2/mg (2.66×10^{-6} m^2/mg)

[Foulant] estimated at 8.20 mg/L average

Model Fitted to percolation decay in Kraemer Basin with OC-28 Water



Model:

Q_o=9 ft^3/ft^2*day

(2.03 m^3/m^2*day)

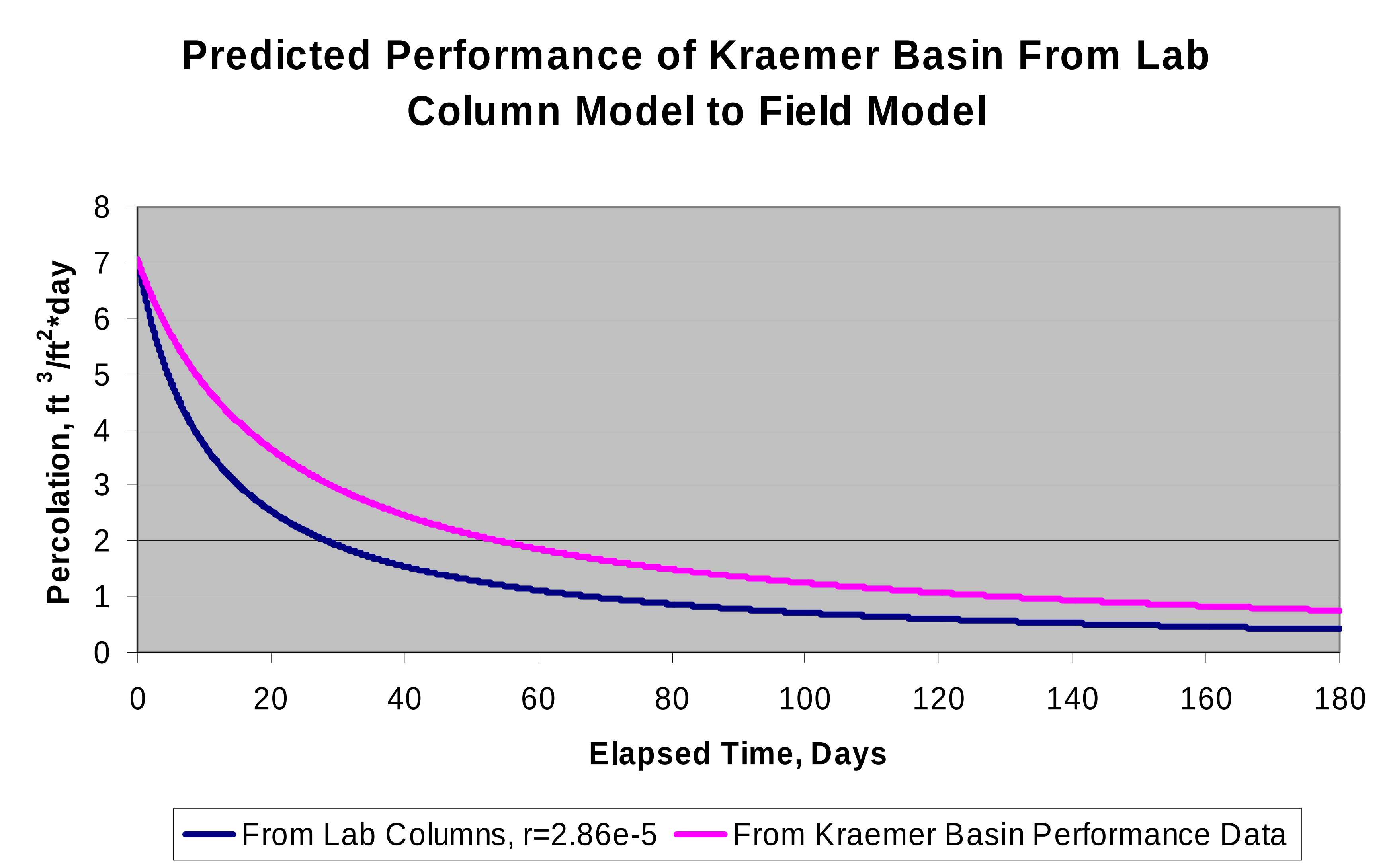
r=2.86x10^{-5} ft^2/mg

(2.66x10^{-6} m^2/mg

Estimated [Foulant] = 0.6 mg/L

In this case, the model described well performance of the basin and predicted the low value of TSS consistent with OC 28 water

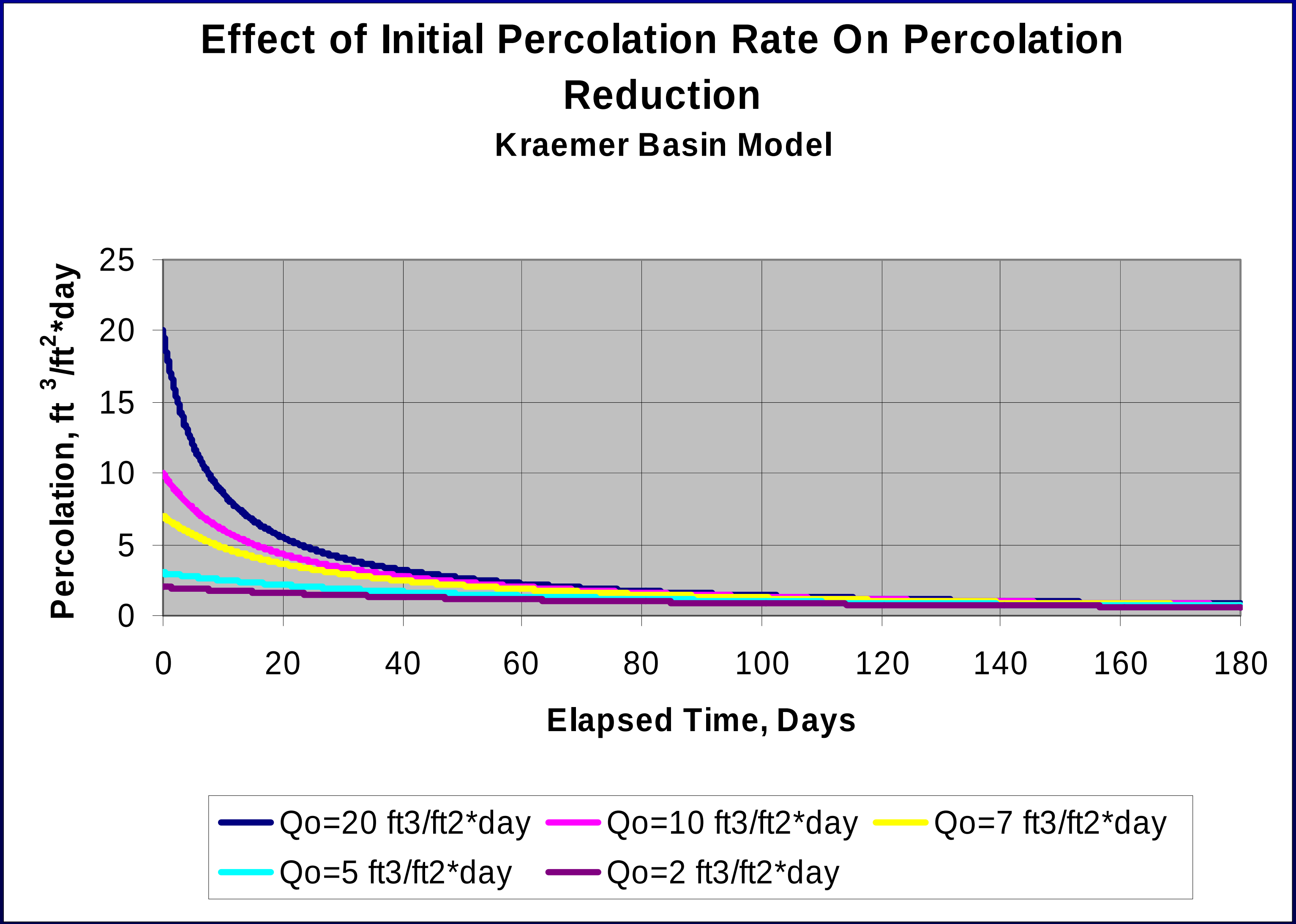
Basin Performance Prediction Made Using Lab Column Model Compares Well With Field Model



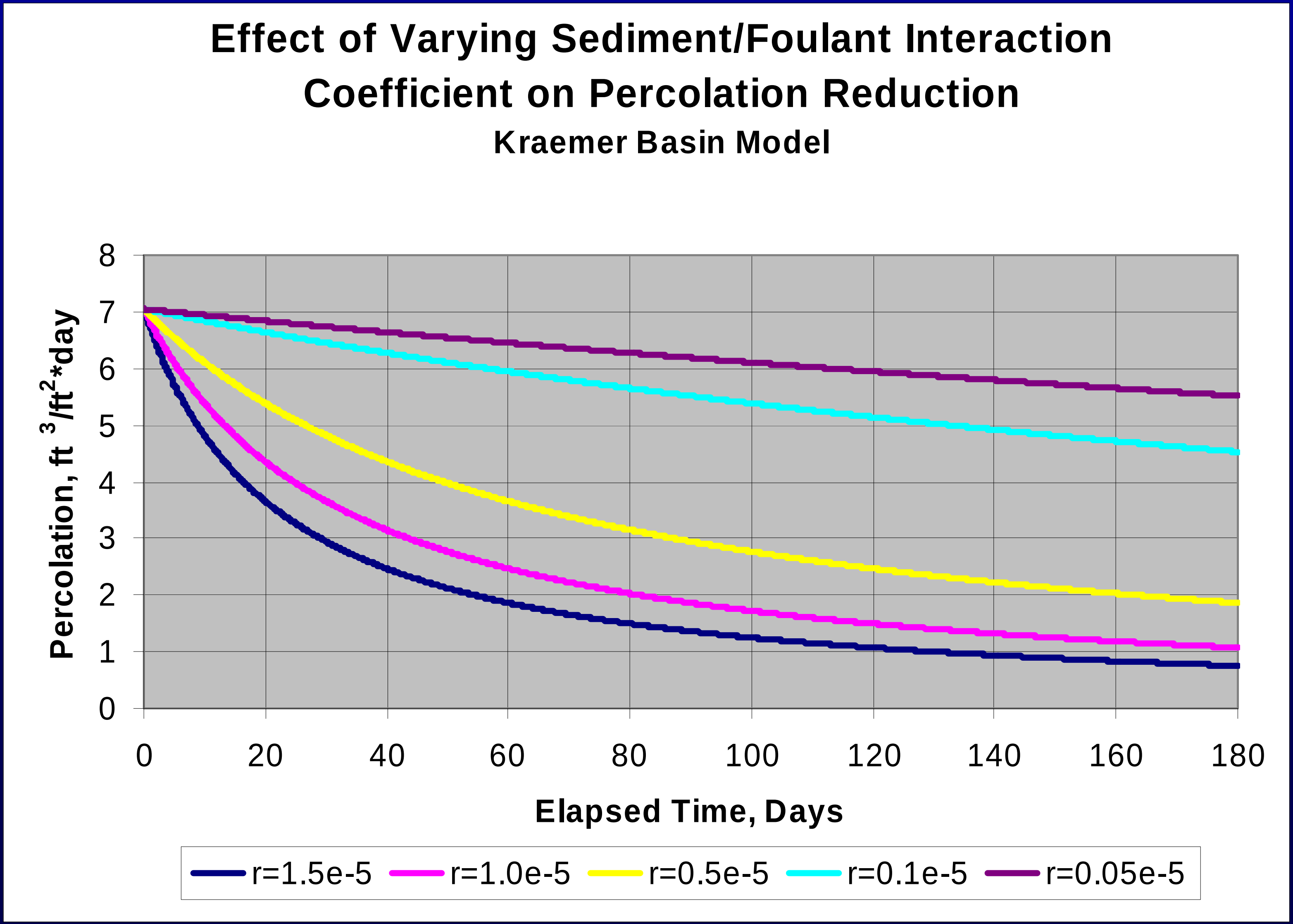
Percolation Decay Model Development Conclusions

- Column and field data support the hypothesis that a simple log decay function based on total solids deposition and a single sediment/foulant interaction coefficient could explain >90% of observed percolation decay.
- The sediment/foulant interaction coefficient was not affected by increasing concentrations of TSS up to 100 mg/L, making possible prediction of months of field kinetics with hours to days using a laboratory column model (i.e., can compress study times).

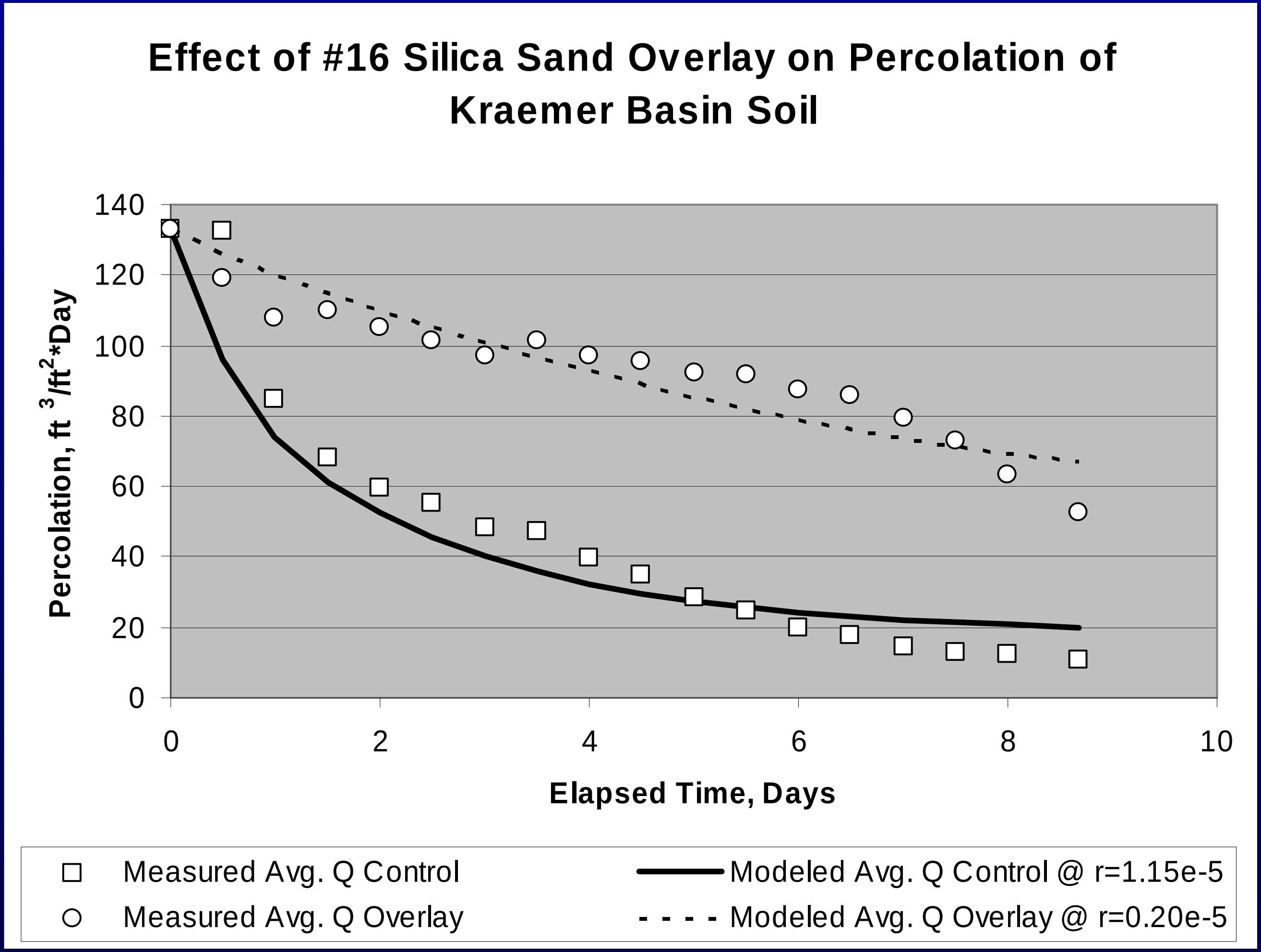
Predicting Effects of Varying the Q_o



Varying the Sediment/Foulant Interaction Coefficient (r)



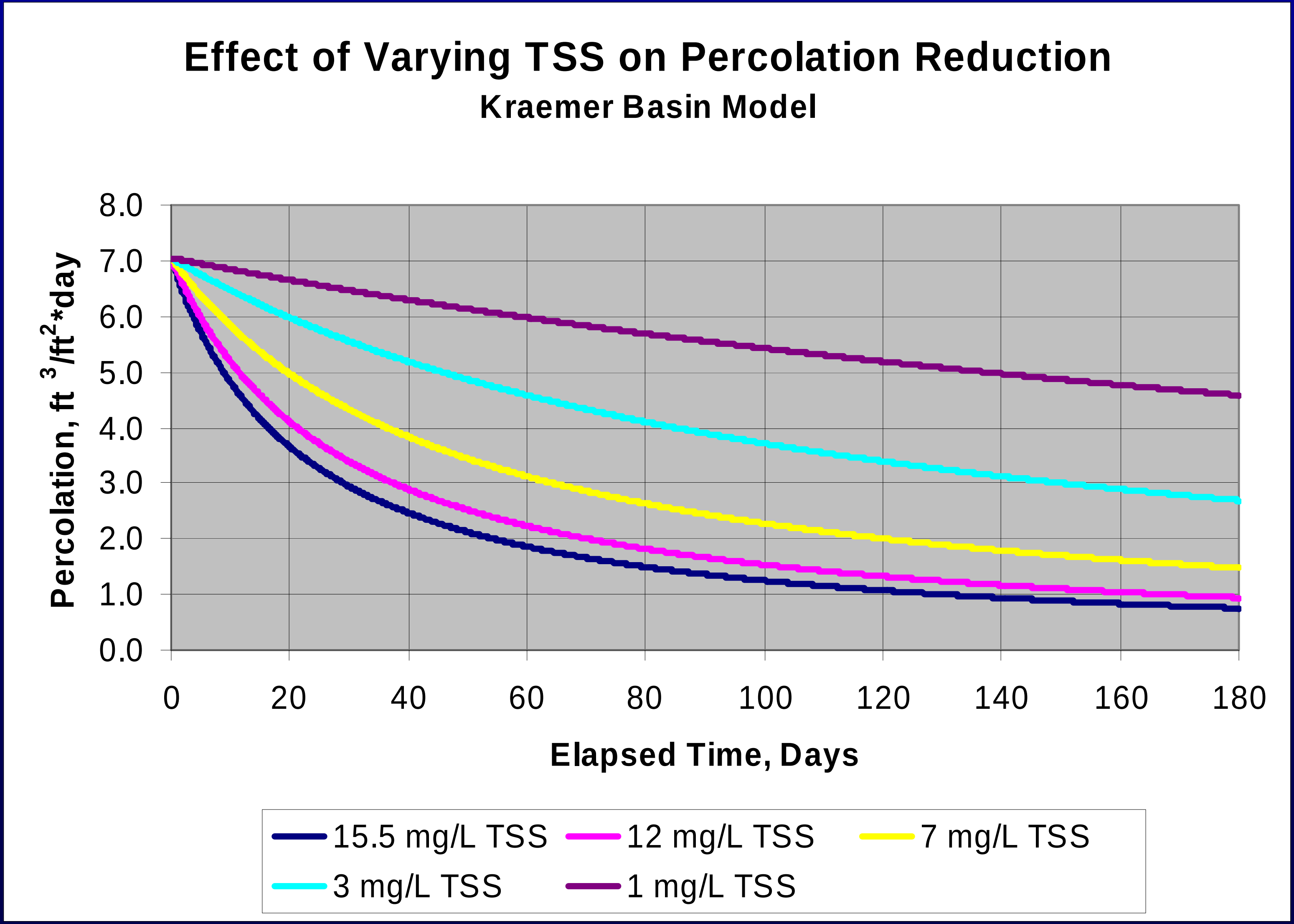
Increasing Average Sediment Particle Size Reduces r (Reduces Percolation Decay).



By increasing the sediment mean soil particle size, the sediment/foulant interaction coefficient (r) is reduced and water production is improved.

Data from a 1988 1" soil column study; TSS presumed to be ~15 mg/L for modeling purposes.

Predicting Effects of Varying the Foulant Loading (TSS)

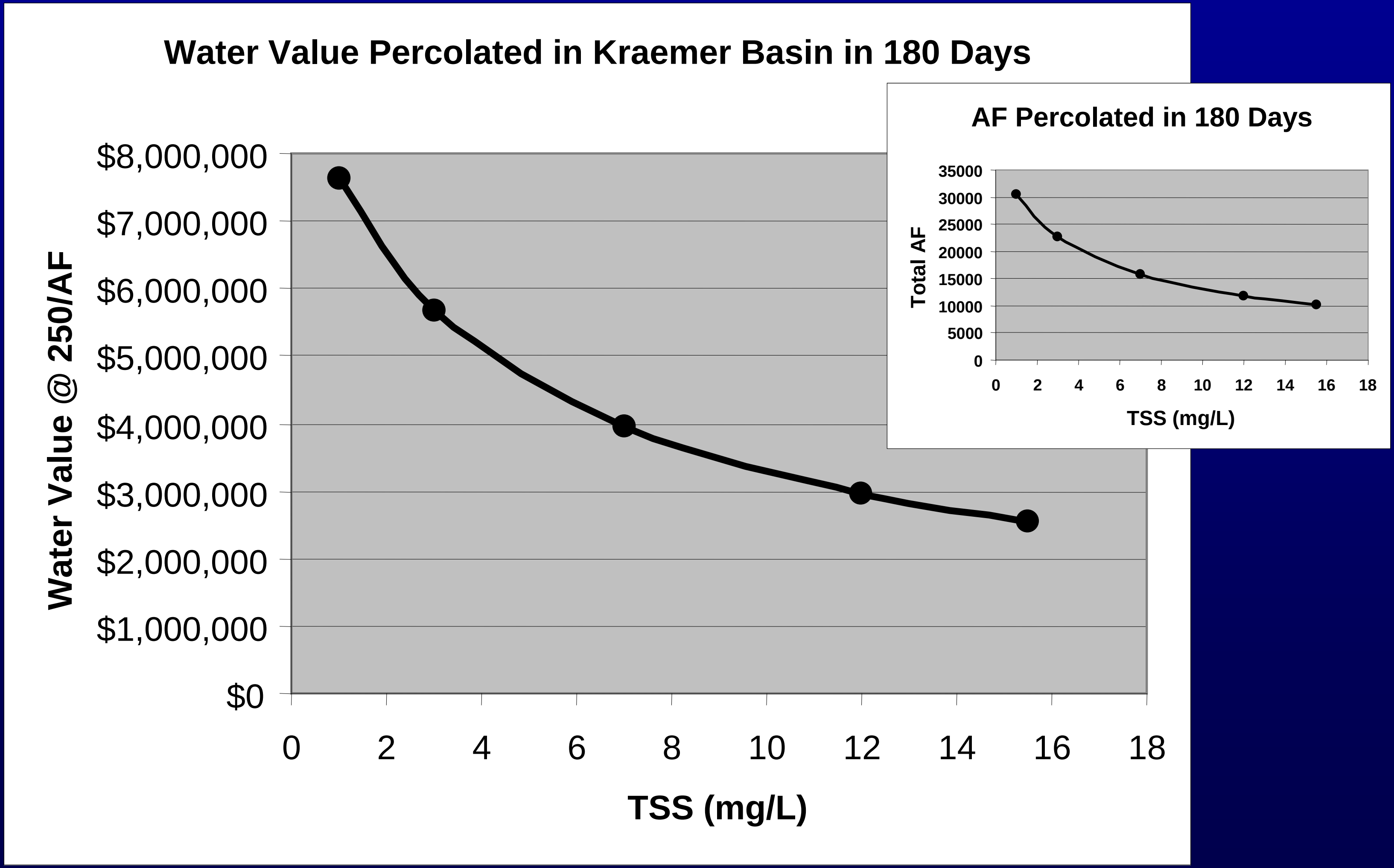


Percolation Model Predictions

- Most benefit in reducing decay obtained by:
  - Reducing soil/foulant interaction coefficient (coarsening surface soil)
  - Reducing foulant load (desilting)

- Increasing initial percolation rate provides least benefit.

Percolation Model Application: *Predicting Effects of Desilting Kraemer Basin*



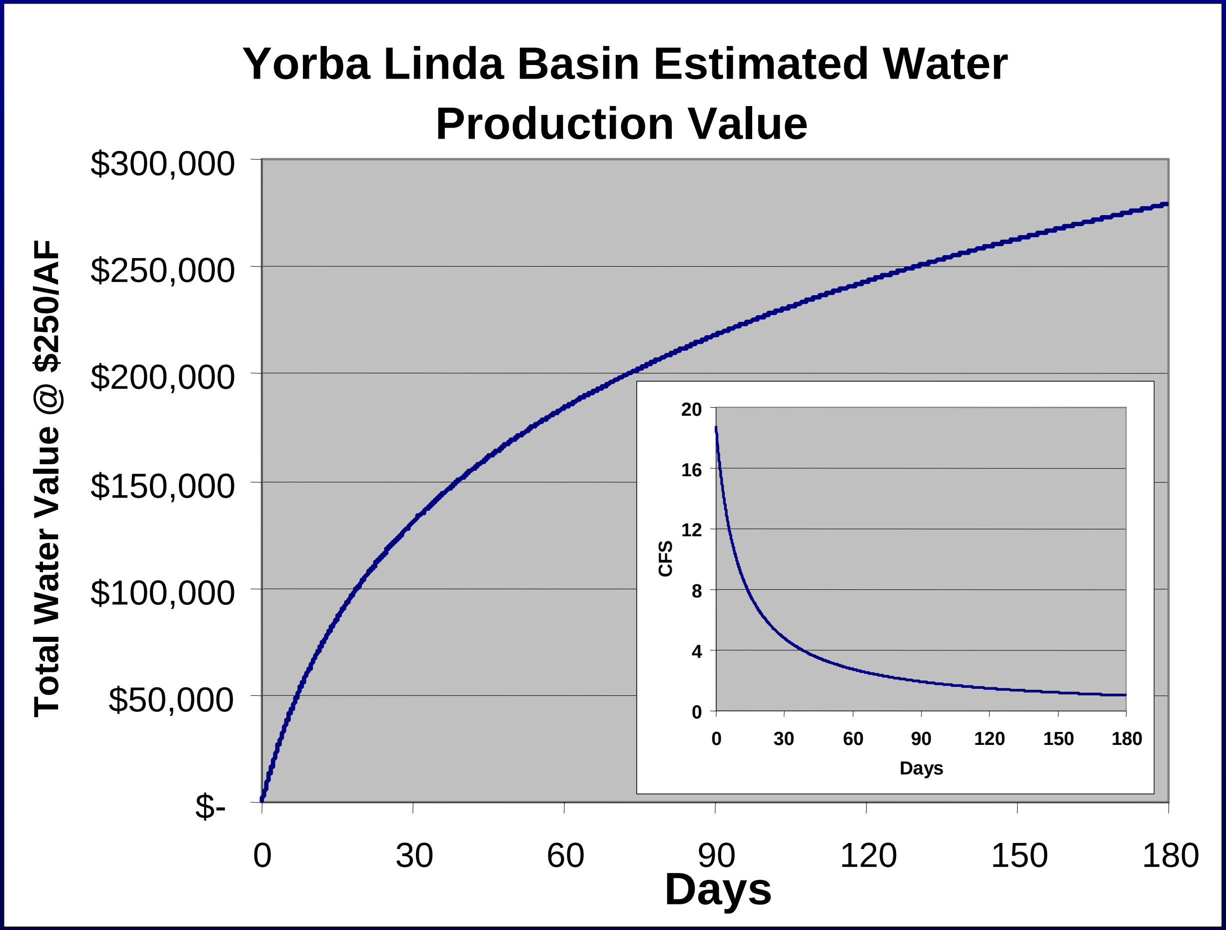
Percolation Model Application: *Predicting Percolation Performance of a New Basin*

Example: Yorba Linda Basin

Model Input Parameters:

- Basin wetted area = 6.2 acres
- Average Initial Percolation Rate (Q_o) = 6 ft^3/ft^2*day
- Average Foulant Loading (TSS) = 20 mg/L
- Sediment/foulant interaction coefficient (r) = 2.86×10^{-5} ft^2/mg
- Time (*t*) period = 180 days
- Time increment (*dt*) = 0.1 days
- Value of water = $250/AF

Percolation Model Application: *Predicting Percolation Performance of a New Basin*



Predicted Basin 180 Day Production:

1,117 acre-feet

Value = $279,376

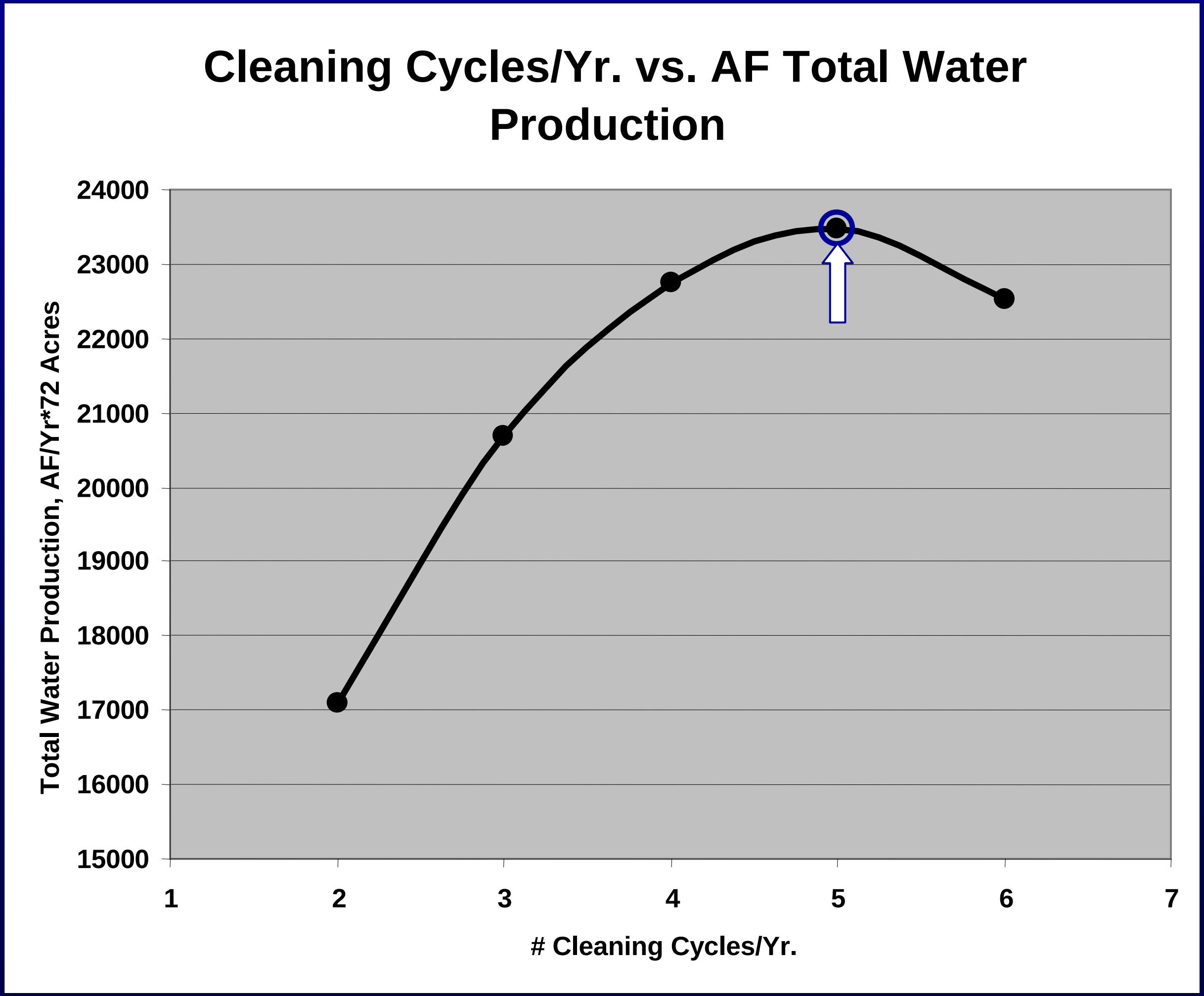
Percolation Model Application:
Predicting Optimum Cleaning Frequency

Example: Anaheim Lake

Model Input Parameters:

- Basin wetted area = 72 acres
- Average initial percolation rate (Q_o) = 3.3 ft^3/ft^2*day
- Average foulant loading (TSS) = 25 mg/L
- Sediment/foulant interaction coefficient (r) = 2.86×10^{-5} ft^2/mg
- Time (*t*) period = Variable, up to 180 days
- Time increment (*dt*) = 0.1 days
- Value of water = $250/AF
- Cost to clean basin $69,812

Percolation Model Application: *Predicting Optimum Cleaning Frequency*

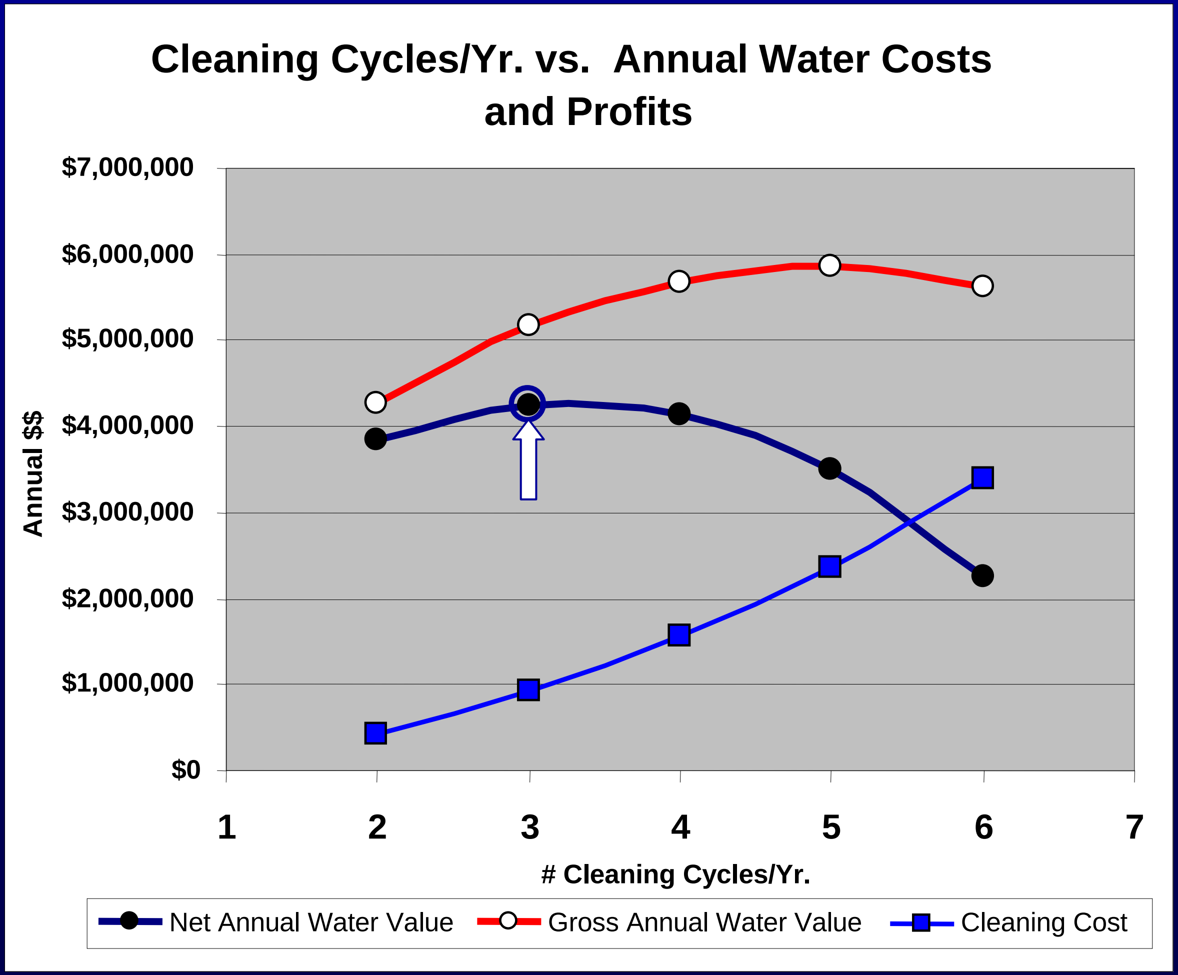


Prediction:

Five (5) cleanings per year would result in maximum annual water production

however…..

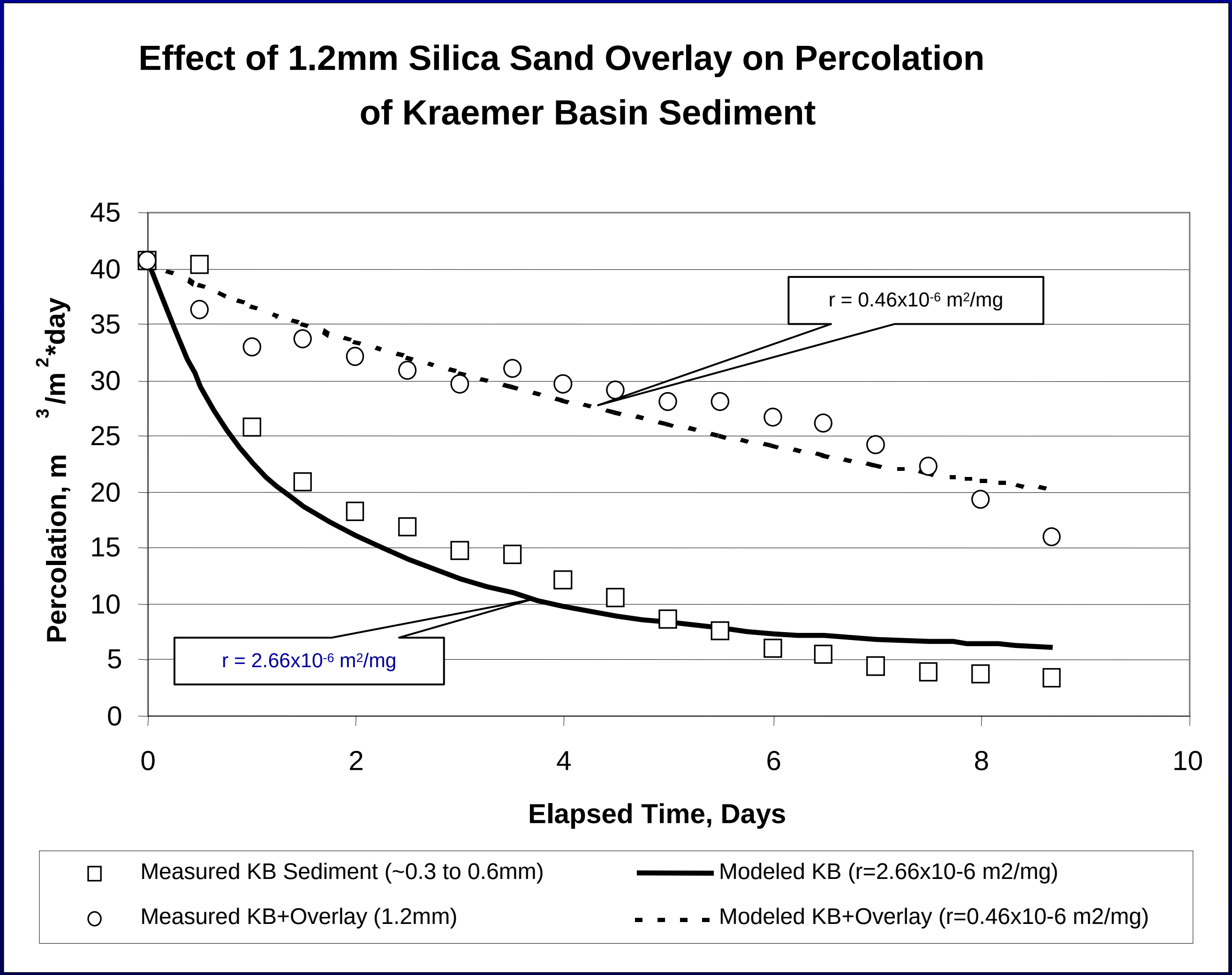
Percolation Model Application: *Predicting Optimum Cleaning Frequency*



<u>Prediction:</u>

…Three (3) cleanings per year would result in maximum annual net water revenue generation

Percolation Model Application: *Optimizing Basin Soil Structure for BCV Operations*

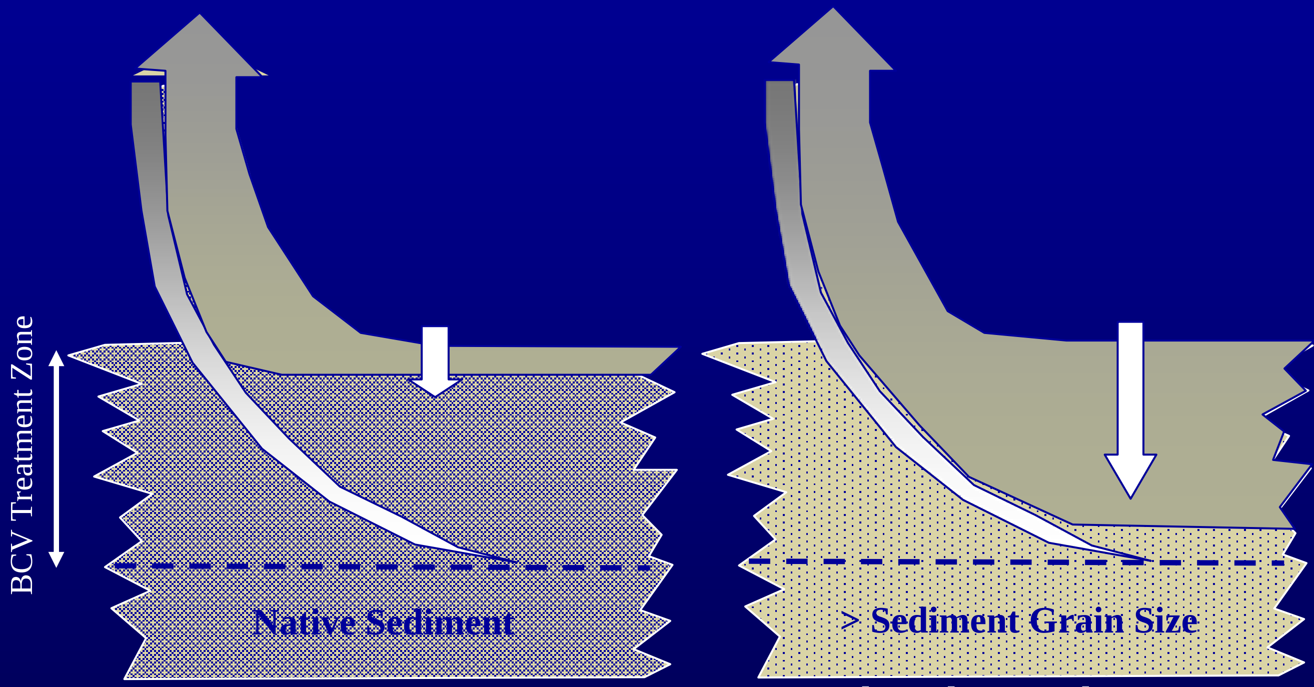


Model Prediction:

Increasing mean sediment particle size at the sediment/water interface reduces the sediment/foulant interaction coefficient (r).

As a result, ***water production is improved over time…***

Percolation Model Application: *Optimizing Basin Soil Structure for BCV Operations*



Foulant deposit shallow, dense, less water permeates over time.

BCV treats much “clean” sediment below foulant layer

Foulant deposit deeper, less dense, more water permeates over time.

BCV now treats mostly fouled sediment

…providing sediment particle size is adjusted to keep foulant deposition within the zone cleaned by the BCV, greater sustainable percolation rates may be obtained.

Modeling relationship between r and foulant penetration will help optimization of BCV operations.

Future Research

Define the nature of foulant contributing to L from:

- laboratory experiments to determine effect of foulant particle size on fouling kinetics
- field measurements of foulant size distribution obtained from operating recharge basins
  - composition and source of the foulant material

Future Research (Cont'd)

- Determine influence of basin sediment structure on the sediment/foulant interaction coefficient (r), specifically:
  - Effects of changing average particle size
  - Relationship between r and penetration of foulant materials

Future Research (Cont'd)

Explore using model to:

- develop methods of real-time prediction of basin performance
- assess potential impact of desilting methodologies on percolation
- optimize basin sediment structure at the sediment/water interface to maximize water production during percolation

- End of Presentation