Sewer System Exfiltration – Understanding the Basics

Webinar, August 6, 2020, 11 am – 1 pm

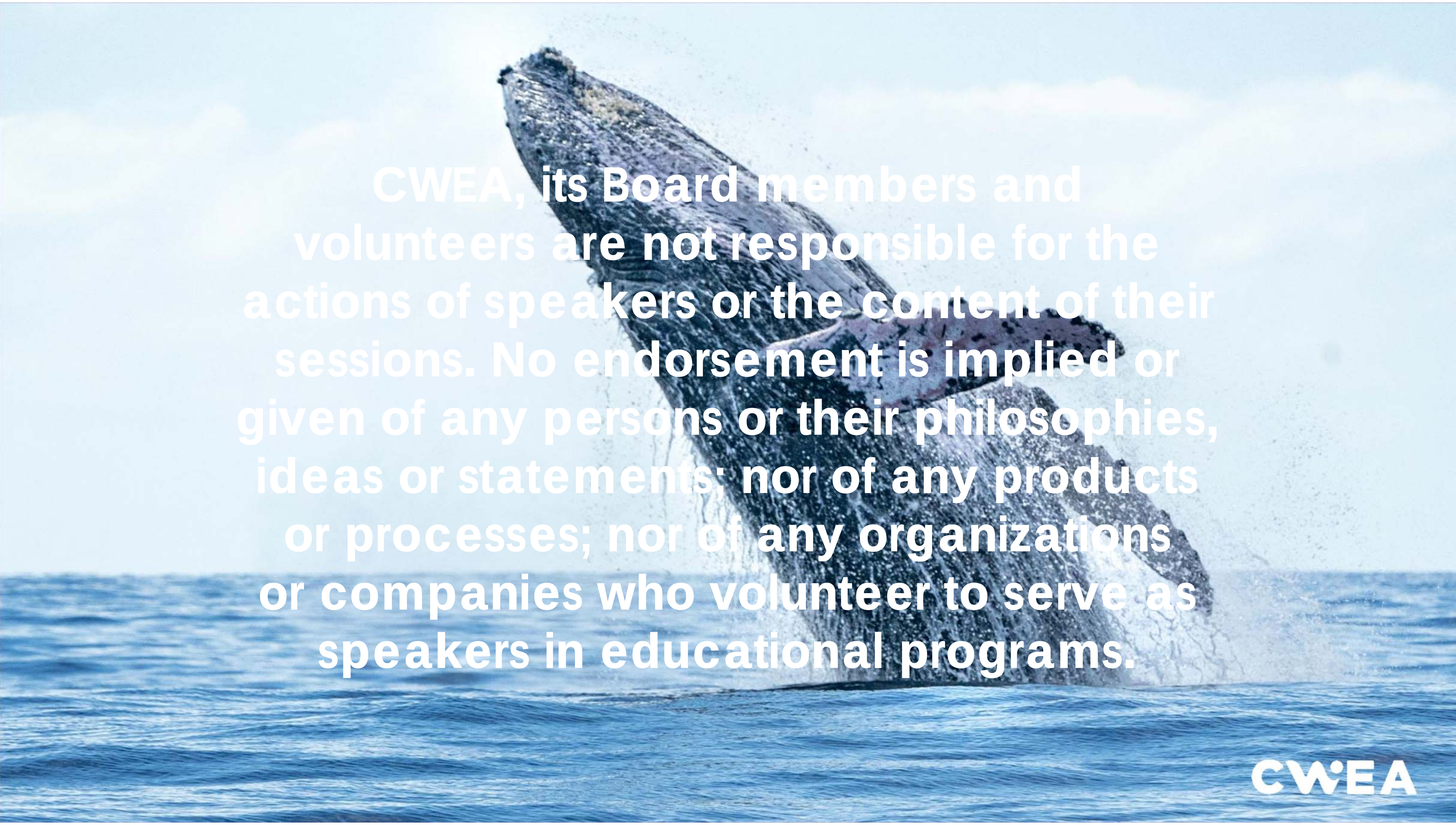
Michael Flores

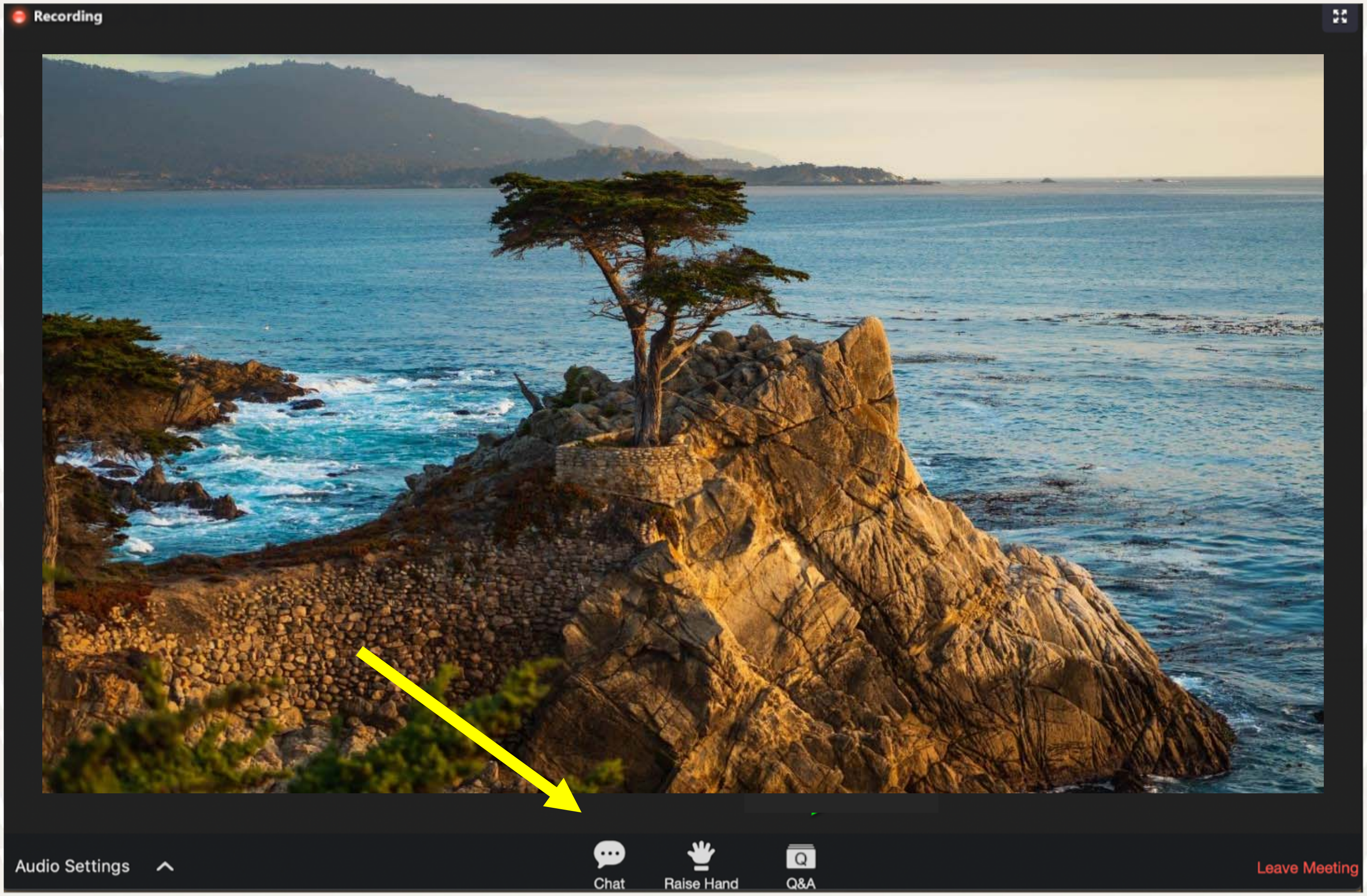
INTRODUCER AND MODERATOR

Practice Area Lead for Collection System Operation, HDR

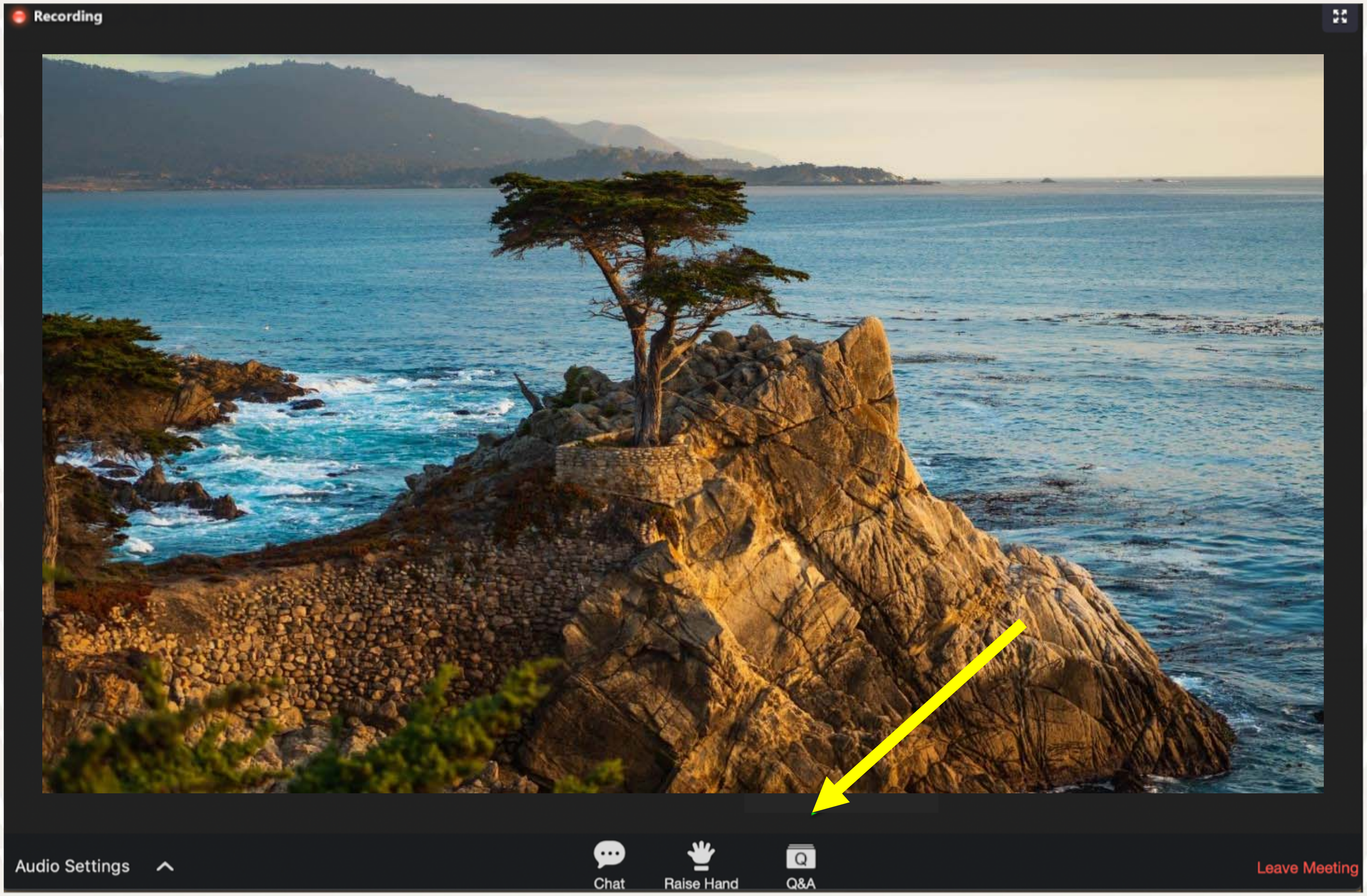
HDR

CWEA

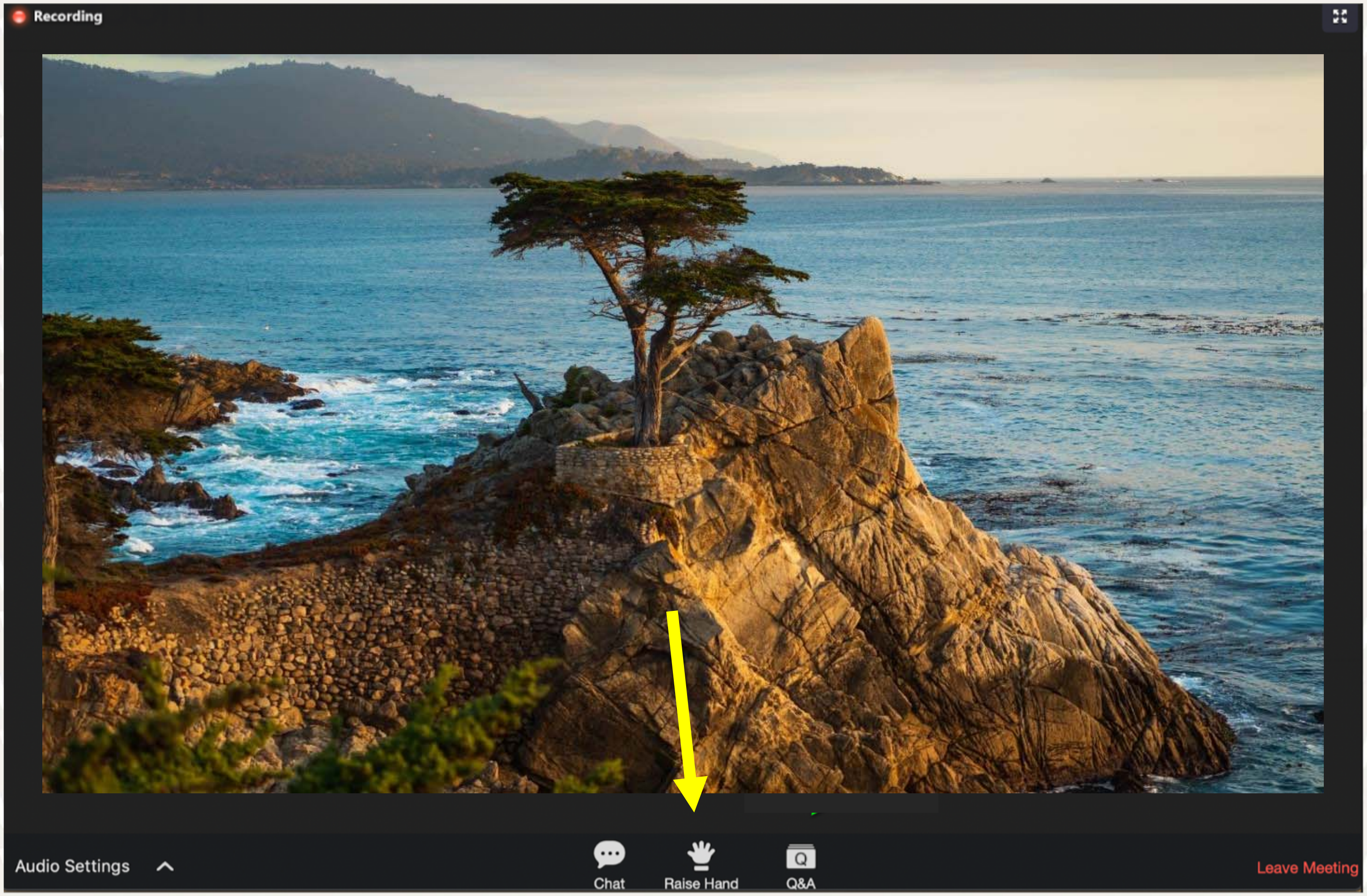

CWEA, its Board members and volunteers are not responsible for the actions of speakers or the content of their sessions. No endorsement is implied or given of any persons or their philosophies, ideas or statements; nor of any products or processes; nor of any organizations or companies who volunteer to serve as speakers in educational programs.
CWEA



Zoom Controls: Chat for Comments



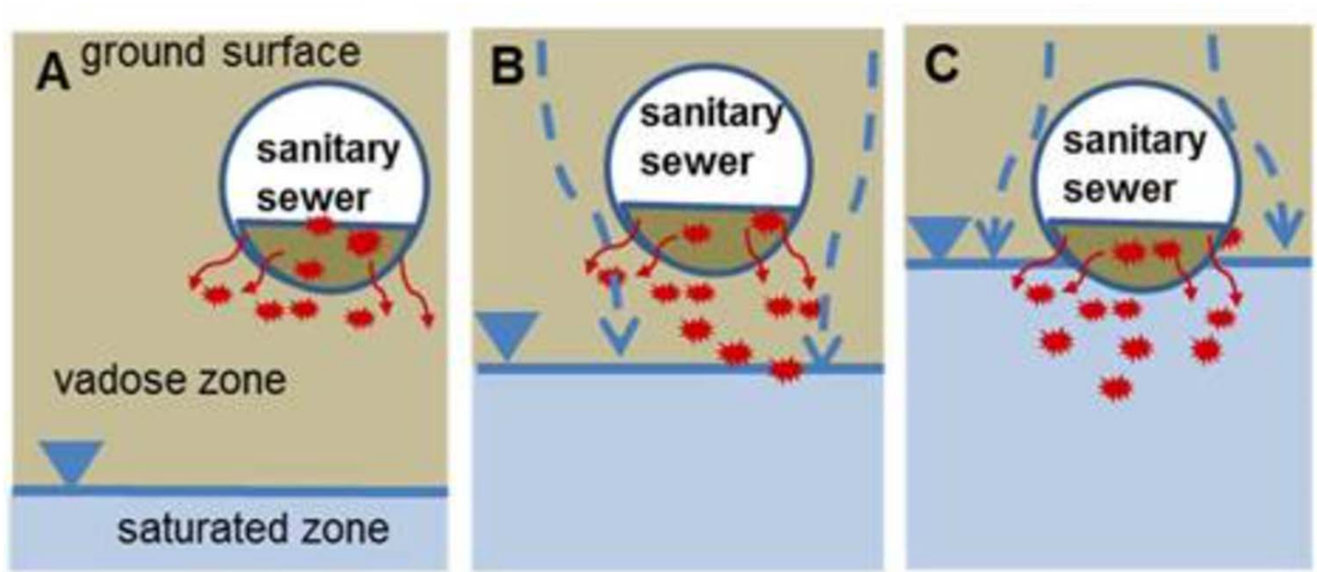
Zoom Controls: Q&A for Questions



Zoom Controls: Raise Hand Feature Not Used in Today's Webinar

Today's Purpose

- Exfiltration
  - Sewage leaving the sewer system into the ground
- Other words used
  - Leakage
  - Sub-surface release

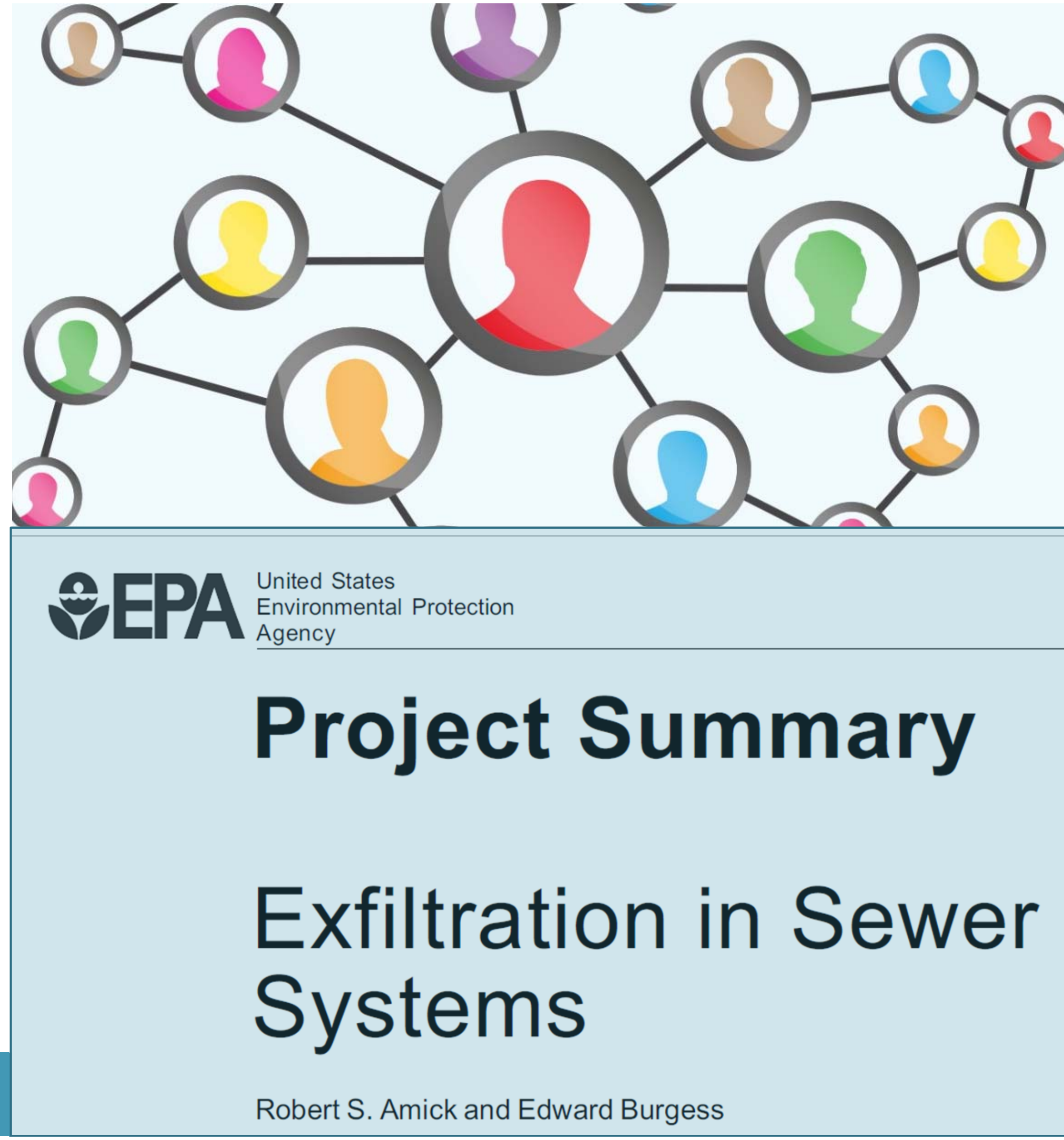


Conceptual models of sewage exfiltration and groundwater infiltration from USEPA's *"Evaluation of Sanitary Sewers as a Source of Pathogen Contamination of Municipal Water Supply Wells"*

https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/9454/report/2012

Today's Purpose

- Start statewide conversation
- Topic of interest for decades
  - Lawsuits against dry cleaners
    - Solvents disposed into sewer
  - EPA studies in early 2000s
    - EPA/600/R-01/034
    - NTIS #: PB2003-103053


EPA United States Environmental Protection Agency

Project Summary

Exfiltration in Sewer Systems

Robert S. Amick and Edward Burgess

Today's Purpose

- Interest in exfiltration has increased
  - Increasingly included in Non-Governmental Organization (NGO) lawsuits
  - Regional Board existing and proposed actions for site-specific impacts on surface water quality
    - San Francisco Bay Regional Water Board
    - San Diego Regional Water Board
  - Some stormwater MS4 NPDES permittees indicating exfiltration as potential pollution source

San Francisco Baykeeper

Santa Barbara Channelkeeper

River Watch

Sewer Agencies

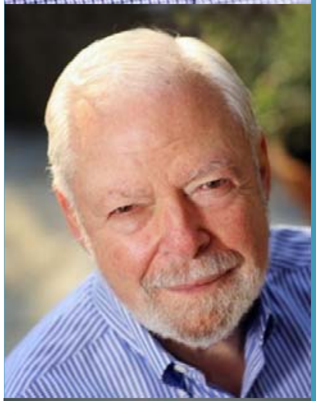
California Water Boards

Stormwater Agencies


Interaction with NGO & Your RWQCB
POLL
QUESTION
CWEA

Agenda for Today & Speaker Introductions

- Part 1 – Why is there a Focus on Exfiltration Today? – Michael Flores, Senior Consultant, HDR



- Part 2 – Exfiltration: Some Basic Concepts – Dr. George Tchobanoglous, Professor Emeritus, UC Davis

- Part 3 – A Talk About Sewer Exfiltration Theory (and the San Diego "Exfiltration" Investigative Order") – Steve Jepsen, Executive Director, SCAP

Learning Expectations

- Why we have a specific focus on sewer system performance
- How exfiltration occurs
- Where sewer system exfiltration causes water quality impacts
- Learn ways to identify, assess and mitigate potential exfiltration where it may impact water quality
- Learn how sewer exfiltration fits into current regulatory discussions

Part 1 - Why is there a Focus on Exfiltration Today?

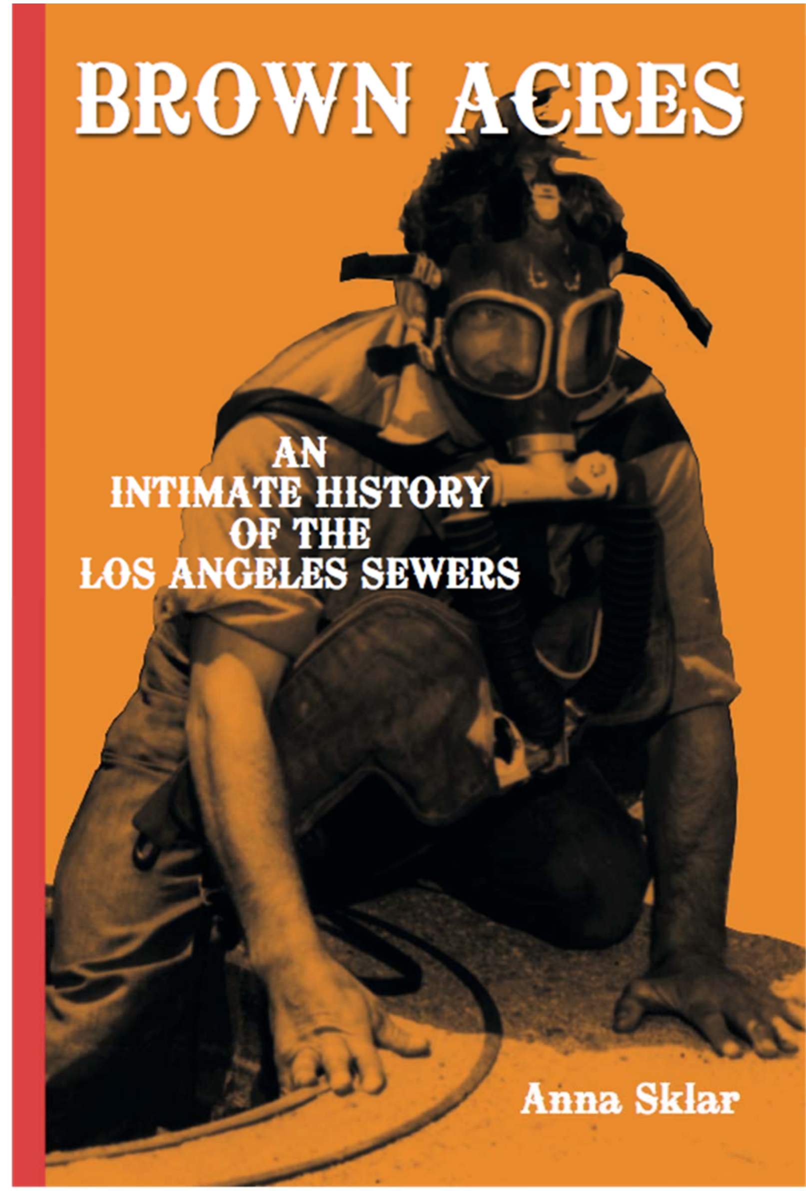
A Little Sewer History from "Brown Acres"

- Book by Anna Sklar
  - NPR reporter
  - Public Affairs Director for Los Angeles Dept of Public Works
  - Avid historian

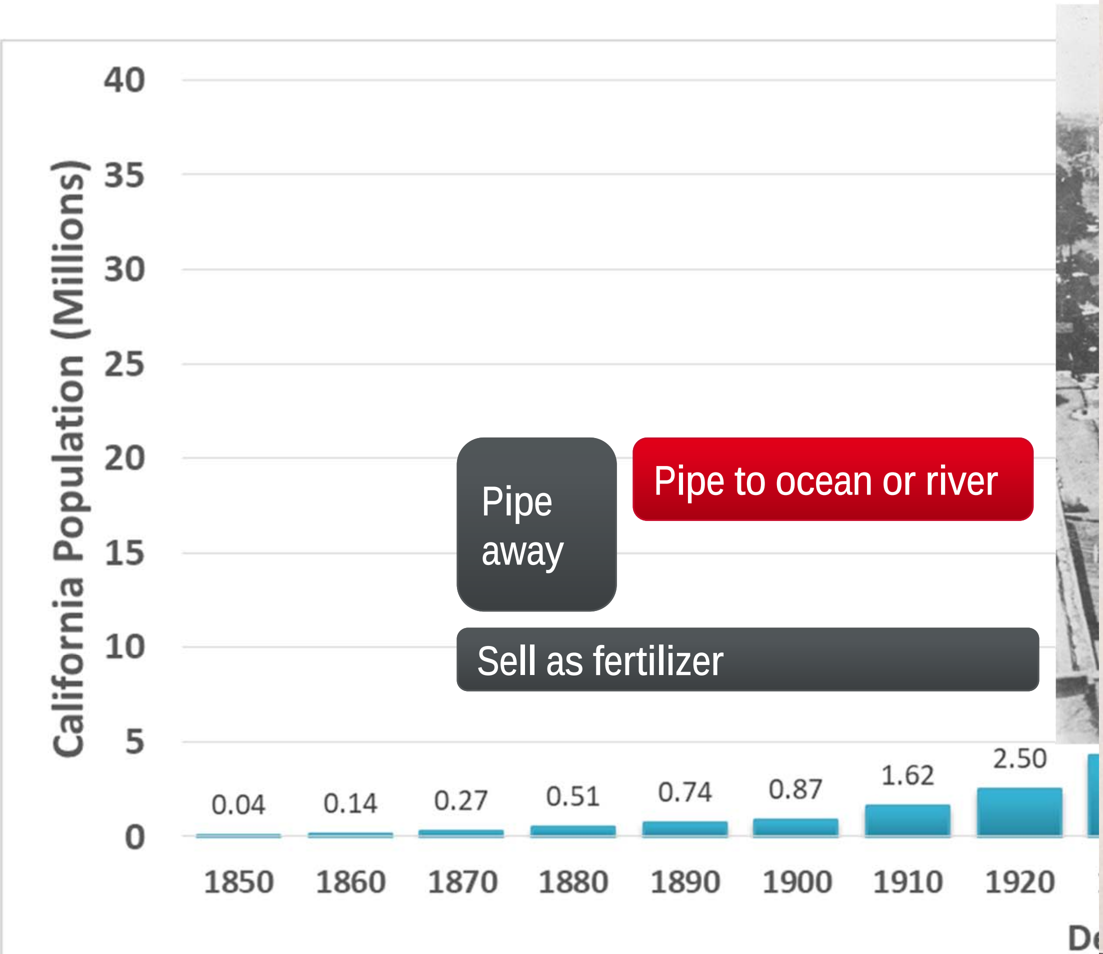
- Details Los Angeles sewer history
  - Politics
  - Decisions
  - Details issues and challenges solved over time

angelcitypress.com/products/brac

https://angelcitypress.com/cart/450100389:1?channel=buy_button



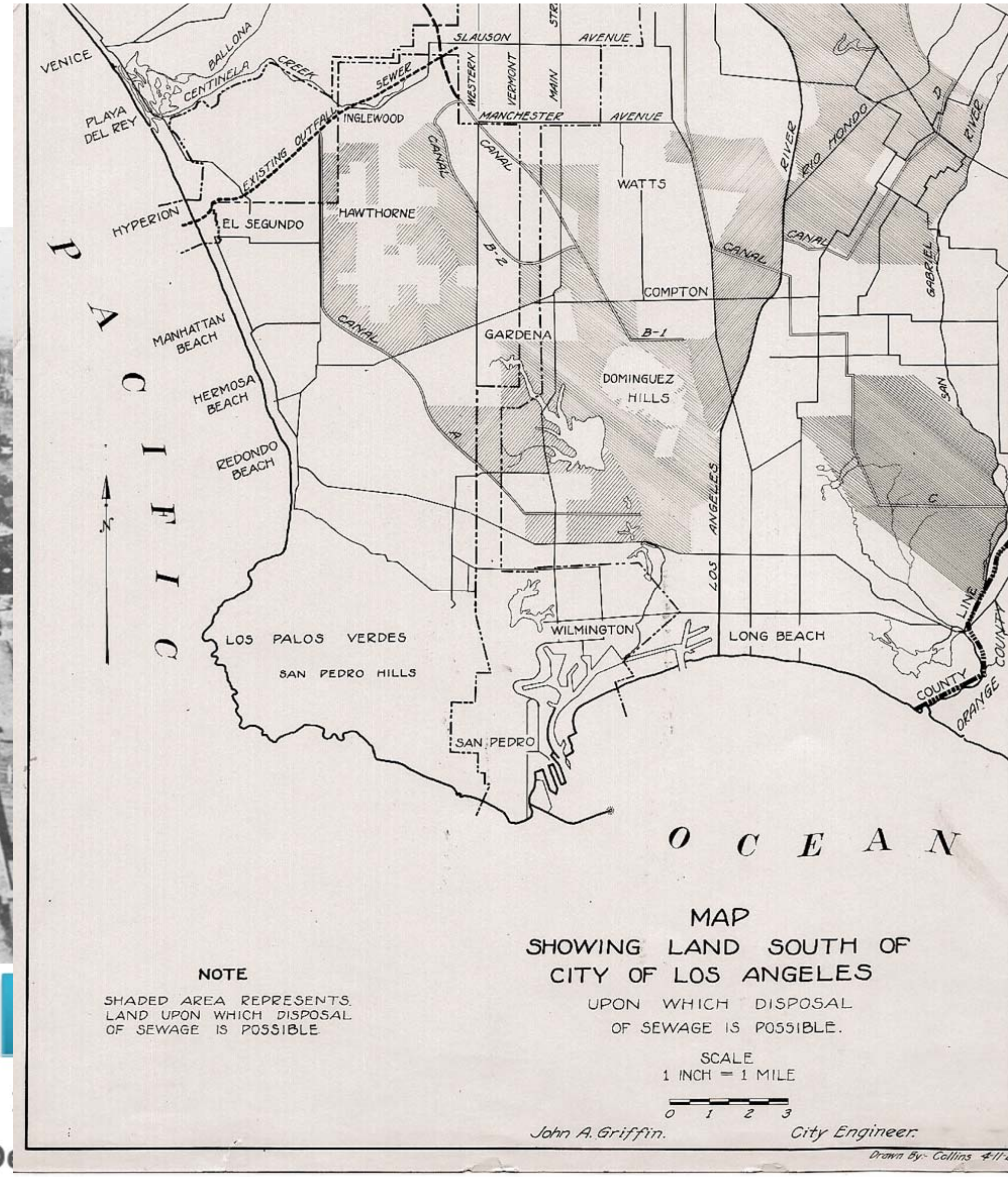
Strategies to Deal with Sewage



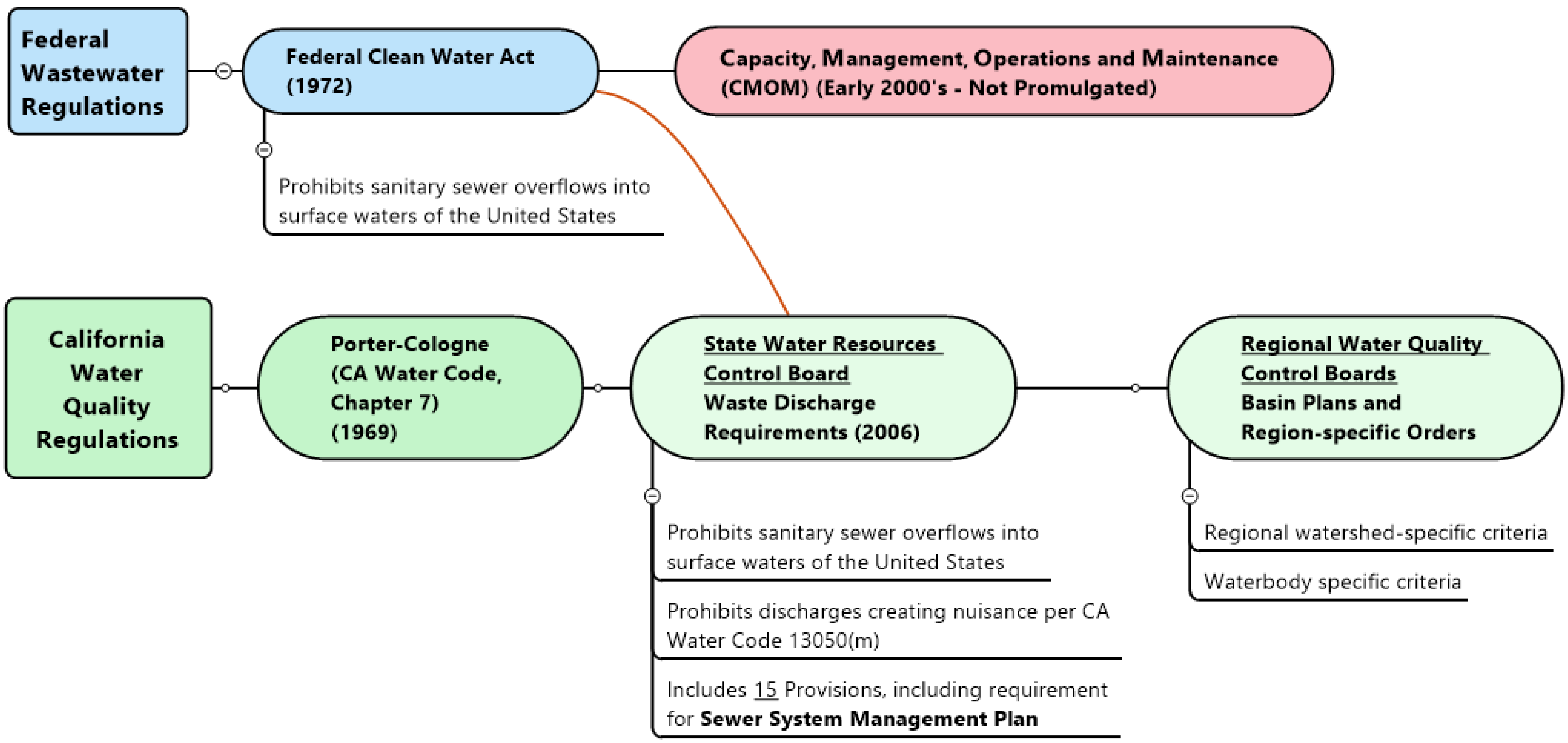
Pipe away

Pipe to ocean or river

Sell as fertilizer



Key Regulations for California Sewer Systems



Federal Clean Water Act

- Regulates pollutant discharges from point sources into the waters of the US
  - NPDES permit for point sources as discrete conveyances
- Regulates quality standards for surface waters
- Discharges from a point source into waters of the US prohibited unless discharged per an NPDES permit
  - Point sources are discrete conveyances such as pipes or man-made ditches.

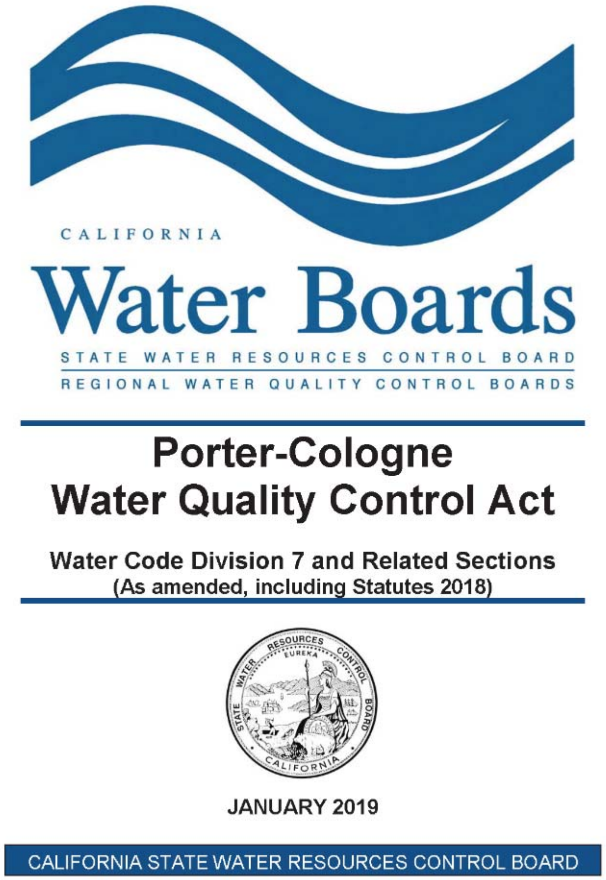
- USEPA develops national water quality for surface waters
  - Requires State and Regional Water Boards to develop state-specific water quality criteria

Federal Clean Water Act and Safe Drinking Water Act

- Regulates pollutant discharges from point sources into the waters of the US **and drinking water supplies**
  - NPDES permit for point sources as discrete conveyances
  - **Drinking water permits for treatment of drinking water**
- Regulates quality standards for surface waters **and drinking water supplies**
- Discharges from a point source into waters of the US prohibited unless discharged per an NPDES permit
  - Point sources are discrete conveyances such as pipes or man-made ditches.

- USEPA develops national water quality **and drinking water pollutant criteria** for surface waters
  - Requires State and Regional Water Boards to develop state-specific water quality criteria **and drinking water criteria**

California Water Code


CALIFORNIA
Water Boards
STATE WATER RESOURCES CONTROL BOARD
REGIONAL WATER QUALITY CONTROL BOARDS

Porter-Cologne
Water Quality Control Act

Water Code Division 7 and Related Sections
(As amended, including Statutes 2018)

JANUARY 2019

CALIFORNIA STATE WATER RESOURCES CONTROL BOARD

- Provides State and Regional Water Boards authority and responsibility to **regulate and protect beneficial uses** of the waters of the State
  - Surface waters, including waters of the United States
  - Groundwater
    - *§ 113. It is the policy of the state that groundwater resources be managed sustainably for long-term reliability and multiple economic, social, and environmental benefits for current and future beneficial uses.*
- Provides that "Beneficial uses" of the waters of the state be **protected against quality degradation**

Beneficial Uses Directly or Indirectly Impacted by Sewage

MUN	*Municipal & Domestic Supply*	Community, military, or individual water supply systems; includes drinking water supply
AGR	*Agricultural Supply*	Farming, horticulture, or ranching; includes to, irrigation, stock watering, or support of vegetation for range grazing
REC1	*Direct Recreational Contact*	Recreational activities with body contact
REC2	*Indirect Recreational Contact*	Recreational activities with close proximity to water
Various Fish and Wildlife-related Uses		Supports cold and warm water ecosystems, preservation or enhancement of aquatic habitats, marine life, vegetation, fish, or wildlife, including invertebrates

Regional Water Board
Water Quality Control Plans (Basin Plans)

- Federal regulations require States to have state-specific water quality control plans
- Each Regional Water Quality Control Board in California has a region-specific Basin Plan
  - o Specifies water quality objectives for surface and ground waters
    - Beneficial uses of the water
    - Water quality criteria to uphold the beneficial uses
    - Antidegradation

State Water Board Resolutions Addressing Statewide Protection of MUN Use

- **Sources of Drinking Water – Resolution 88-63**
  - All surface and ground waters of the State:
    - Considered to be suitable for MUN uses
    - Should be designated for MUN uses by the Regional Boards (with specific exception)
  - https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2006/rs2006_0008_rev_rs88_63.pdf

- **Human Right to Water – Resolution 2016-1010**
  - Human right to water is a core value
  - Adopted as a top priority for the Water Boards.
  - Encourages consideration of human right to safe water in all activities and regulatory actions that could affect existing or potential sources of drinking water (MUN)
  - https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2016/rs2016_0010.pdf

State Water Board Resolutions Addressing Statewide Protection of MUN Use

- **Sources of Drinking Water – Resolution 88-63**
  - **All surface and ground waters** of the State:
    - Considered to be **suitable for MUN** uses
    - **Should be designated for MUN** uses by the Regional Boards (with specific exception)
  - https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2006/rs2006_0008_rev_rs88_63.pdf

- **Human Right to Water – Resolution 2016-1010**
  - **Human right to water is a core value**
  - **Adopted as a top priority** for the Water Boards.
  - Encourages consideration of human right to safe water in all activities and regulatory actions that could affect existing or potential sources of drinking water (MUN)
  - https://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2016/rs2016_0010.pdf

Sewer System Exfiltration Concerns are System-Specific

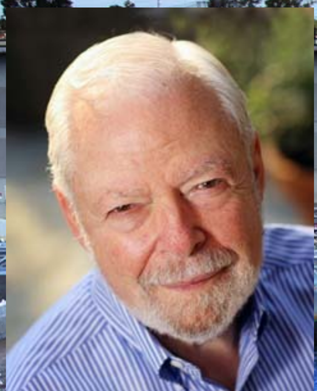
- Localized geographical and hydrological conditions
  - Proximity to surface water body
  - Groundwater aquifer levels
  - Soil types
  - Watershed hydrology (i.e. connectedness of groundwater to surface waters)

- System-Specific Causes
  - Pipe condition
  - Pipe material
  - Pipe construction
    - Pipe sags
    - Defective joints
  - Localized ground movement
    - (i.e. earthquake, mudslides, subsidence)
  - Operation and maintenance practices
    - Pipe degradation accelerated by high pressure or mechanical
    - Excessive tree roots

The Big Picture

- We collectively own 100,000* miles of mainline sewers in California worth ~$100B
  - What are the issues to address with this infrastructure?
  - To what extent is exfiltration one of those issues?
  - When is it worth spending money to address potential exfiltration?

*Based on analysis of sewer agency data in CIWQS



Dr. George Tchobanoglous

SPEAKER

Professor Emeritus, UC Davis Department of Civil and Environmental Engineering

Exfiltration: Some Basic Concepts

CWEA Webinar
SEWER SYSTEM EXFILTRATION

August 6, 2020

George Tchobanoglous
Professor Emeritus
Department of Civil and Environmental Engineering
University of California, Davis

Topics

- Definition of exfiltration
- Types of wastewater sewers
- Where does exfiltration occur
- Background information on sewer pipe materials and joints
- Estimating exfiltration
- The movement of exfiltrated water
- Assessment and maintenance of sewers

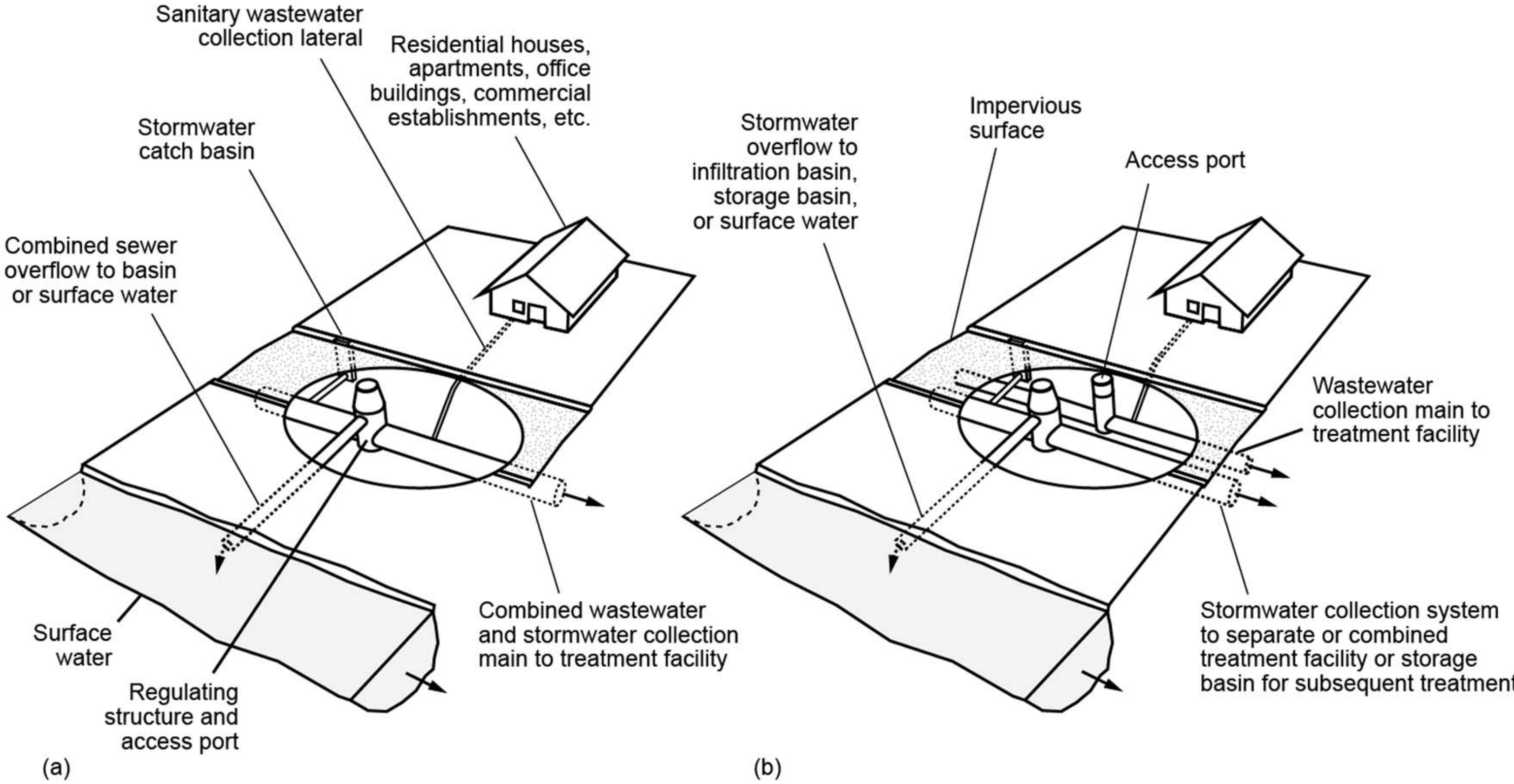
Definition of Exfiltration

Flow out of a collection system (sewer) through breaks or cracks in the pipe wall, defective pipe joints or connections, eroded pipe due to corrosion, openings caused by root growth, and breaks in access port (manhole) connections and walls

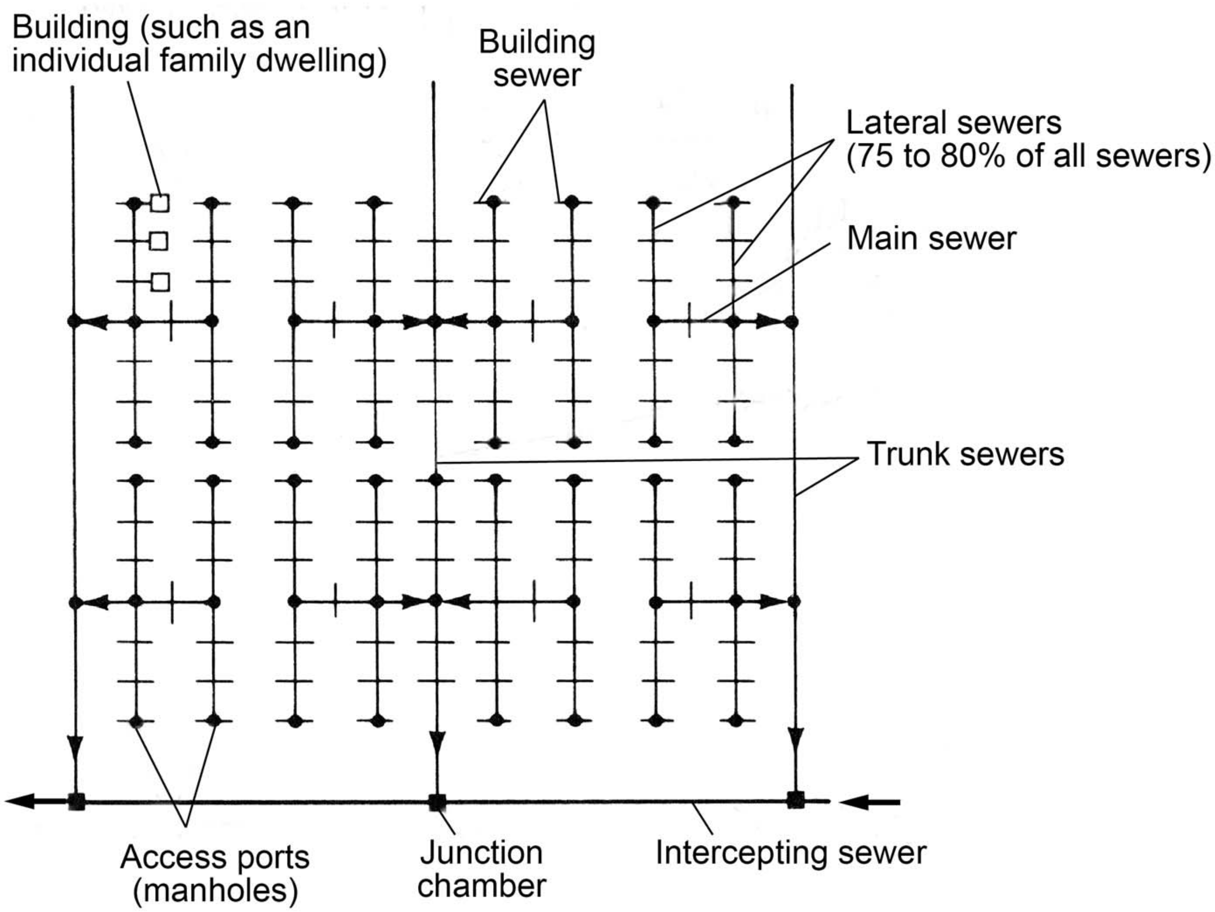
Some Historical Facts and Observations Concerning Exfiltration

1. The early sewers were constructed in the Eastern United States where high groundwater conditions are common. As a result, exfiltration was not considered a serious issue.
2. In fact, some writers noted that infiltration would help flush the sewers and dilute the wastewater
3. There were no acceptance standards, rather quality control during construction was stressed.

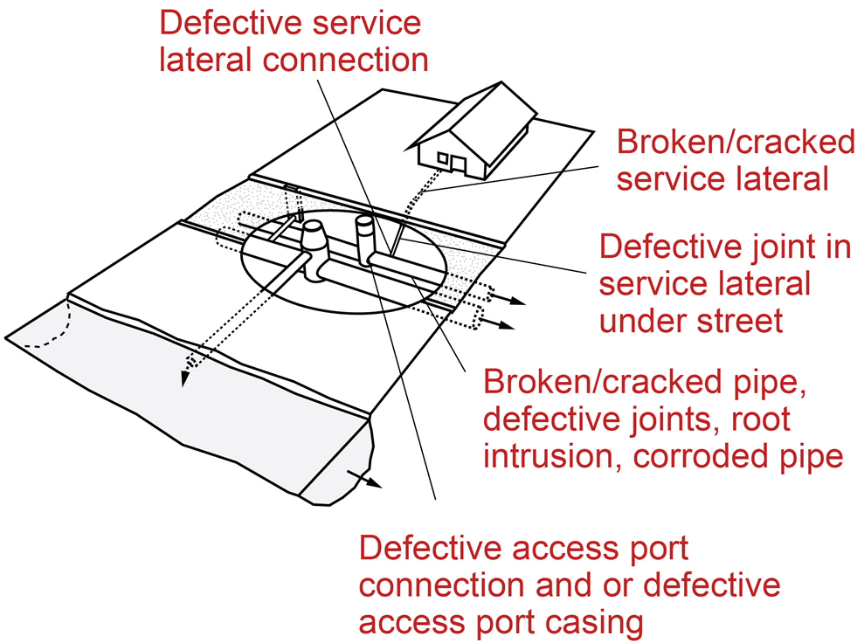
Definition Sketch for Combined and Separate Wastewater Collection Systems

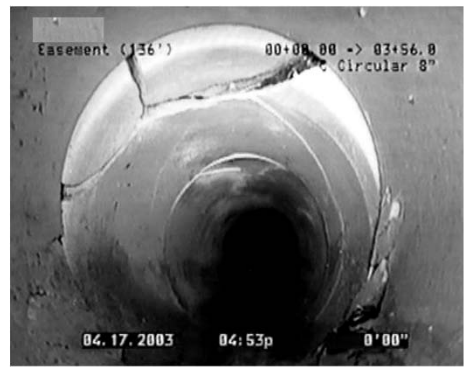


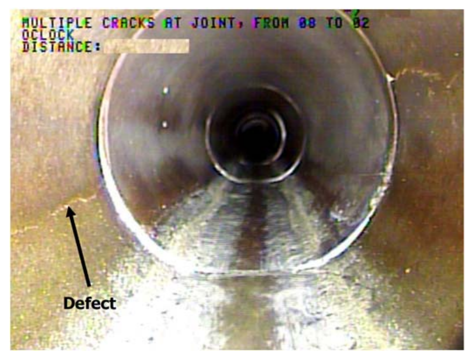
Classification of Sewers in Separate Wastewater Collection System



Definition Sketch for Exfiltration from Separate Wastewater Collection System








Service Laterals
POLL
QUESTION

Criteria for Selection of Wastewater Collection Pipes

Criteria	Requirement
Strength	Ability to withstand daily stresses
Durability	Must resist deterioration due to weather, moisture, or chemicals found in wastewater
Imperviousness	Must be impervious to admission of groundwater or exfiltration of wastewater
Smoothness	To enhance the flow of wastewater and to avoid the accumulation of deposits
Hardness	To resist erosion from grit in wastewater
Uniformity	To avoid projections and irregularities at joints
Joints	Must remain watertight
Cost	Must be cost effective with respect to other sewer components

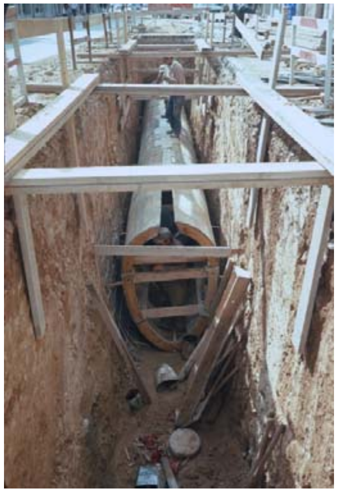
Types of Materials Used for Wastewater Collection Systems, Part 1

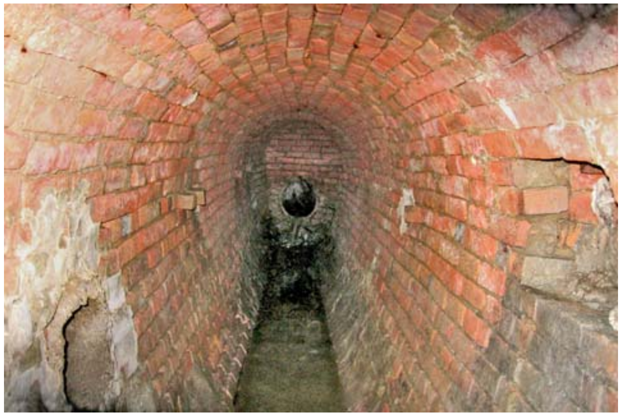
Sewer material	Comment
Clay pipe	Used throughout the world, but of varying quality.
Vitrified clay pipe (VCP)	Relatively inexpensive resist corrosion and abrasion are smooth and durable but are bulky and difficult to transport and handle. Brittleness can make it more prone to cracking and root intrusion. Joints are susceptible to chemical attack. Modern VCP pipe is nothing like the clay pipe used in the 1950s and 1960s, primarily because of the new joint materials (see slide No. 13).
Steel (cast iron, ductile iron, and galvanized iron)	Cast iron pipes are most commonly found in older homes, Steel is much heavier and more expensive than other materials. Because of weight, short sections are required and leading to more opportunity for joint failure. Electrolytical and other types of corrosion are common.
Wood pipes	Wood stave or hollowed out pipes were used for both water and wastewater in the ninetieth century. Wood pipes are still found as sewer lines are being replaced.
Bituminized fiber pipe (Orangeburg pipe)	Made of cellulose wood fiber held together with water-resistant adhesive and impregnated with liquified coal tar pitch (most common color of pipe is black). Lightweight and easy to work with, but weak and prone to failure. Most of the Orangeburg sewers have been replaced due to failure of partial collapse.
Masonry (bricks)	The first brick and mortar sewer constructed in the Indus Valley in northwestern regions of South Asia, ca 2500 BC.

Types of Materials Used for Wastewater Collection Systems, Part 2

Sewer material	Comment
Concrete	Strong, smooth, and light weight must be reinforced in beyond 600 mm. Requires careful installation to avoid cracking
Asbestos cement	Made with a mixture of asbestos fiber, silica, and cement. First manufactured in the early 1930s. Brittle and subject to deterioration with the release of asbestos fibers. More commonly used in water supply. It is estimated that more than 400,000 miles of asbestos cement may still be in use. No longer used for sewers.
Reinforced concrete	Strong, smooth, and light weight must be reinforced in beyond 600 mm. These pipes are subject to corrosion where acid discharges are carried in the sewer and where hydrogen sulfide can form under septic conditions
Cast in place reinforced concrete	Where conditions require the use of non-standard sections of sewer pipe
Plastic (PVC and ABS)	Smooth surface, excellent carrying capacity resistant to tree root intrusion, must be supported properly to to avoid bending and or collapse.
High density polyethylene (HDPE)	Used increasingly because of its durability, flexibility and corrosion resistance. The most common material used for sewer repair. The material of choice for force mains. Used extensively in Europe.


Construction of a Cast-In-Place and a Brick Egg-Shaped Sewer

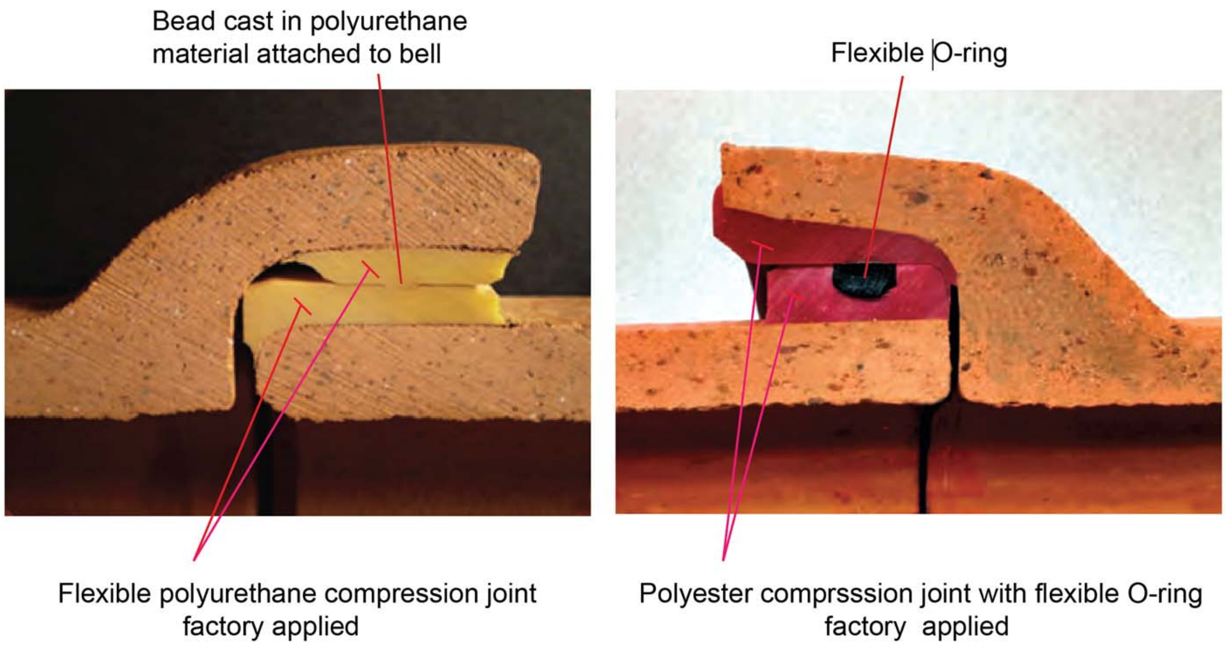




Types of Joint Materials and Methods in Use Over the Past 150 Years for VCP

Joint material	Comment
Cement	Used in early sewers in England and Germany in the 1800s. Cement joint offered no flexibility.
Sulfur, tar, and sand	First used in England and widely adopted for use in the United States without the tar. Joint is rigid once formed.
Asphalt and tar	Used extensively in Germany; also, some usage in the United States. Joint material melts where hot water is discharged to sewer.
Oakum and cement mortar	Oakum is a rope-like material made from oiled jute or hemp fibers. Cement mortar is applied after hemp in packed into bell of pipe. Joints were rigid and not resistant to earth movement. In common use until after World War II.
Hot pour compounds	Bitumastic compounds, GK (Vulcanized linseed oil and anhydrous clay which served as the binder) and JC-60 a plastic based compound have all been used
Prefabricated compression joints	Polyurethane attracted to bell and spigot. Polyester and O-ring joint for bell and spigot pipes. Polyester resin cast onto the bell portion of the pipe and the spigot end is cast with a grove or gland. During the late 1950s to the mid 1960s, PVC was also used for joint material.
Flexible rubber coupling	Use for coupling VCP to each other and to other types of pipe. Most commonly used for repairing broken pipes.

Most Commonly Used Joints for Vitrified Clay Pipe Since the Passage of the CWA in 1972



Adapted from the National Clay Pipe Institute

Maximum Allowable Leakage for Exfiltration

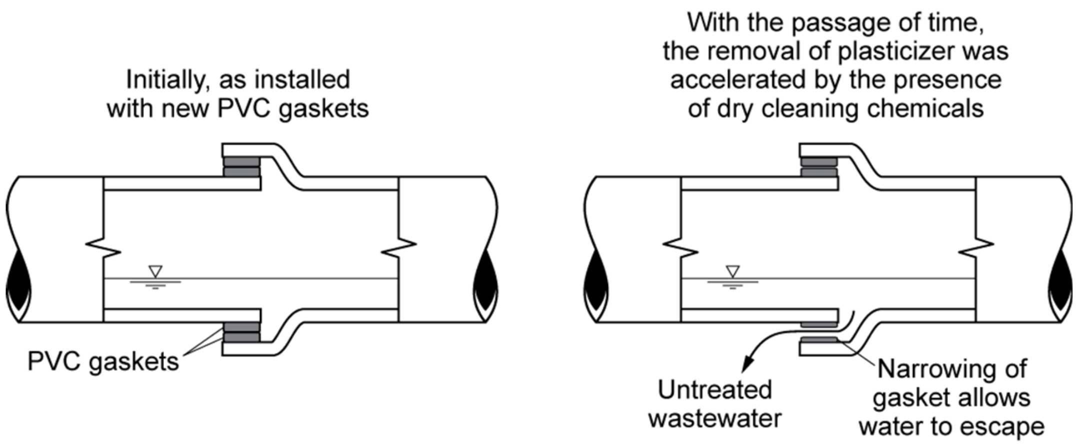
- In the early 1900s, a leakage (exfiltration) rate of 50,000 gal/mi•d, without regard to size, was common. There was no standard for exfiltration at the time
- By 1980, an exfiltration rate of 200 gal/in-dia•mi•d was in use for new sewers
- In the 21st century an exfiltration rate of 50 gal/in-dia•mi•d is now in common use for new sewers

---

"The total exfiltration, as determined by a hydrostatic head test, shall not exceed 50 gallons per inch diameter per mile of pipe per 24 hours at a minimum test head of 2 feet above the crown of the pipe at the upstream manhole or 2 feet above the groundwater elevation, whichever is greater." Courtesy City of Galveston, TX

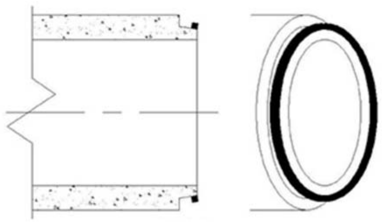
Public Health and the Environment Impact of Defective Pipe Joint Material

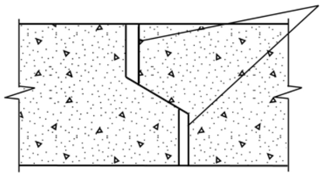
Consider the effects of using PVC formed with varying amounts plasticizer for clay pipe joint material (circa 1958 - 1965)



Most Commonly Used Joints for Concrete Pipe Since the Passage of the CWA in 1972

Joint material	Comment
Rubber gasket	A rubber gasket is utilized for concrete joints with a grove or offset on the spigot and or bell joints
Perform flexible joint sealants	Bitumen and butyl sealants are applied to the tongue or spigot and inserted into the bell or grove
Mortar tongue and groove	A layer of cement paste or mastic mortar is placed in the lower portion of the bell or groove of the installed pipe and on the upper portion of the tongue or spigot of the pipe section to be installed.
External sealing bands	Sealing bands are designed to be wrapped around the exterior of the joint to provide resistance to infiltration and/or exfiltration.





Factors Effecting Exfiltration from Separate Wastewater Collection Systems

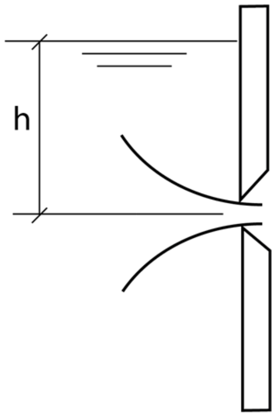
Physical/biological	**Environmental**
Age of sewer	Type of bedding material
Size of sewer	Colmation in bedding material
Materials of construction	Type of soil (coefficient of permeability)
Construction quality, type of pipe joint	Root growth into sewers, especially during draught conditions
Location of sewer damage (defect)	Damage in the upper portion of the sewer pipe may not lead to exfiltration
Depth of flow in sewer	Depth to groundwater
Accumulations in sewer	Location of frost line
Wastewater constituents	Average rainfall
External loading conditions	Intensity of rainfall events

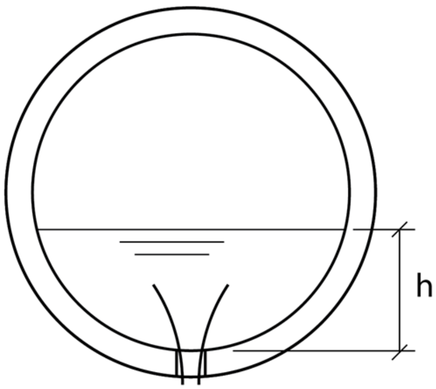

Increased Deposition
POLL
QUESTION
CWEA

Public Health and the Environment Potential Impact of a Leaky Sewer

- Consider a sewer leak of 600 gal/d caused by small crack (e.g., 1/4 in diameter hole with a water head 0.5 ft (see later computation)
- If the coliform count is 10^9/100 mL and the water quality requirement for a water body is 240/100 mL
- Then, hypothetically, **2,500,000,000** gal/d of water can be contaminated

Estimating Exfiltration from a Sewer





DISCHARGE THROUGH AN ORIFICE

$$Q = C_c C_v A\sqrt{2gh}$$

Where C_c = coefficient of contraction, unitless
C_v = coefficient of velocity, unitless
A = area of orifice, ft^2
g = acceleration due to gravity, ft/s^2
h = head of water, ft

Estimate the discharge through a crack with an equivalent open area corresponding to a circle with a diameter of ¼ in subject to a head of 0.5 ft

Assumptions:

$C_c = 0.60$

$C_v = 0.8$ due to unevenness of the cracked perimeter

$Q = (0.6)(0.8)[(3.14/4)(0.25/12)^2]\sqrt{(2)(32.2)(0.5)}$

$Q = (0.6)(0.8)(3.41 \times 10^{-4})(5.67) = 9.28 \times 10^{-4}\ ft^3/s$

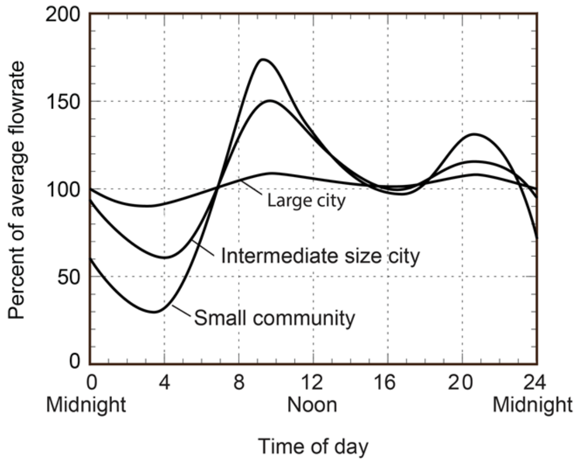
$Q = (9.28 \times 10^{-4}\ ft^3/s)(86{,}400\ s/d) = 80\ ft^3/d$

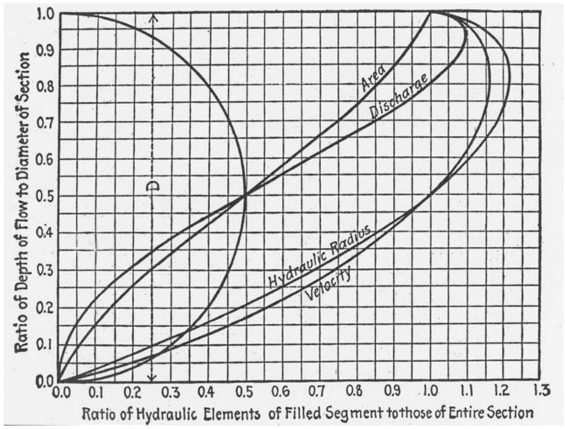
$Q = (80\ ft^3/d)(7.48\ gal/ft^3) = 600\ gal/d$

Q = (600 gal/d)(365 d/yr) = 219,000 gal/yr

Note: Applies to newly broken pipe, or broken pipe not subject to continuous inundation and solids accumulation

Limitations in Estimating Exfiltration from a Sewer



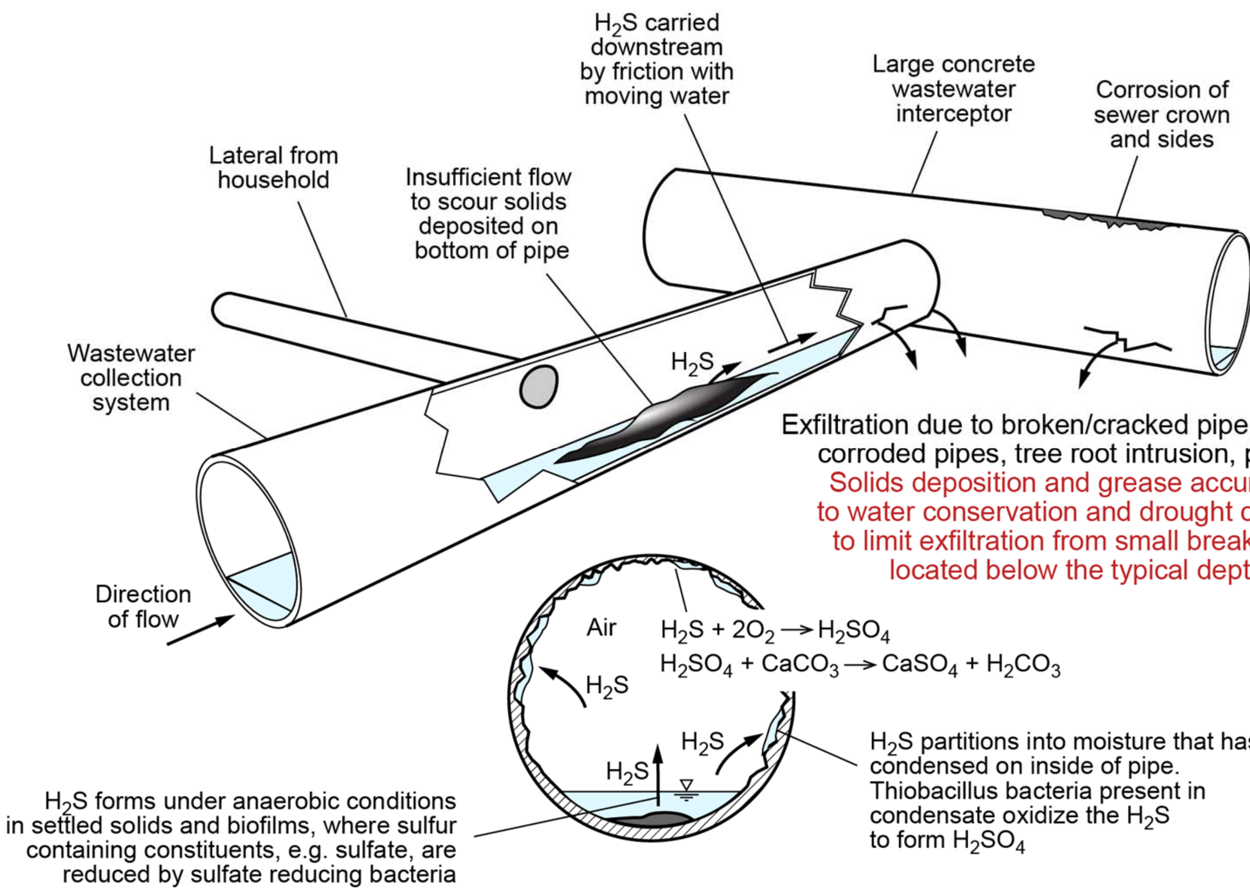


FACTORS IN ASSESSING EXFILTRATION

1. Hourly variation in wastewater flow as a function of community size and size of sewers
2. Long-term flowrate reduction due to conservation
3. Type of leak (crack in pipe wall, broken pipe, leak at pipe joint, root growth, leaks at access port) and dimensions of leak
4. Accumulation of solids, grease, and biological material in the bottom of sewer forming a low permeability layer
5. Nature of the bedding material and whether periodic water barriers were used
6. Biological growth in bedding material forming a low permeability colmation layer

Taken together these factors can reduce the computed rate of exfiltration, using the orifice equation, from cracks in the sewer by a factor varying from 50 to 80 percent. Typical reductions for broken pipe and joints can vary from 25 to 60 percent.

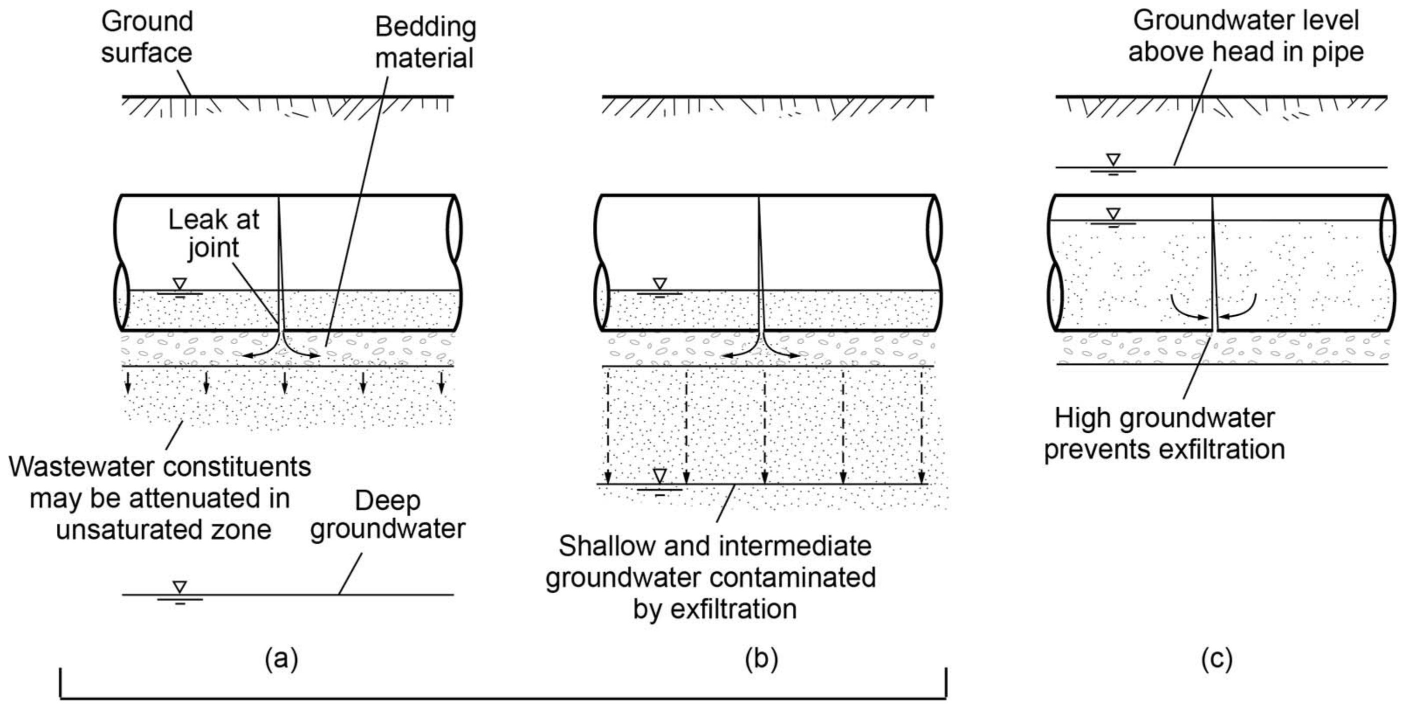
Impact of Water Conservation on Solids Deposition, H_2S Formation, and Downstream Corrosion and Exfiltration



Exfiltration due to broken/cracked pipe, defective joints, corroded pipes, tree root intrusion, pipe corrosion.

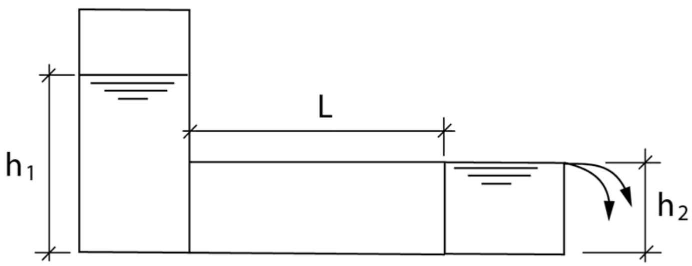
Solids deposition and grease accumulation, due to water conservation and drought conditions, tend to limit exfiltration from small breaks and cracks located below the typical depth of flow

Where Does Exfiltrated Wastewater Go?



Note: In some cases where exfiltration occurs, wastewater may travel horizontally in the bedding trench similar to effluent distribution in a septic tank leach field

Darcy's Equation for Estimating Flow Through a Permeable Medium



Darcy's Equation

$$Q = -KA\frac{h_2 - h_1}{L}$$

Where Q = discharge, ft^3/s

K = coefficient of permeability, ft/s

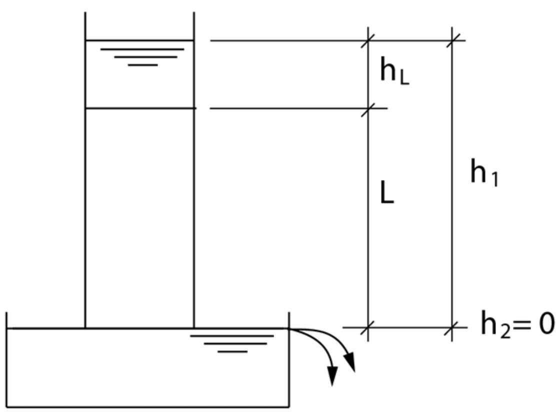
A = area, ft^2

h_2 = hydraulic head at outlet, ft

h_2 = hydraulic head at inlet, ft

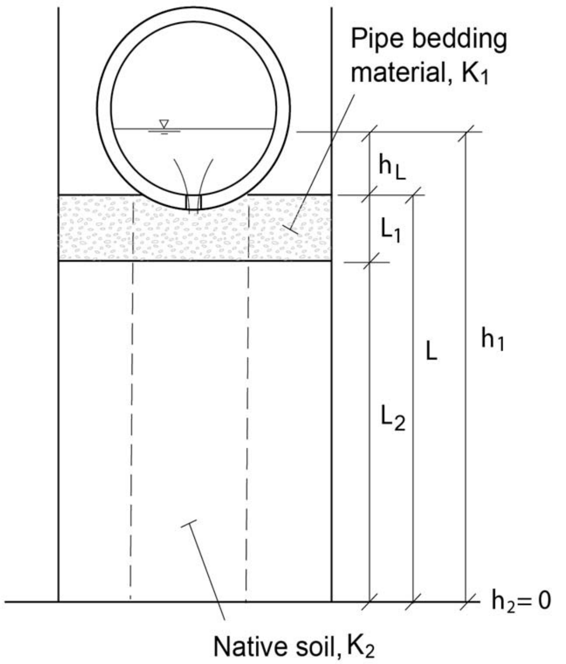
L = length of soil sample, ft

The minus sign is used to denote that the flow is from a higher to a lower potential



Porous medium	Permeability range	
	cm/s	ft/s
Gravel	10^2 -10^0	3.25 – 3.25×10^{-2}
Sand	10^0 -10^{-2}	3.25×10^{-2} – 3.25×10^{-4}
Fine sand, silt, losses	10^{-2} -10^{-3}	3.25×10^{-4} – 3.25×10^{-5}
Silty clay	10^{-3}-10^{-5}	3.25×10^{-5} – 3.25×10^{-7}
Clay	<10^{-6}	<3.25×10^{-8}

Estimating Flow Through Layered Soil



For flow perpendicular to a layered soil, the average coeffieient of permeability can be computed using the following expression

$$\bar{K} = \frac{L}{\sum_{i=1}^{n}\left(\frac{L_i}{K_i}\right)}$$

DARCY FLOW EXAMPLE

$$Q = -\bar{K} A \frac{h_2 - h_1}{L}$$

Referring to the figure on the left

$K_1 = 3.25 \times 10^{-4}$ ft/s (bedding layer)

$K_2 = 3.25 \times 10^{-6}$ ft/s (native soil, silty clay)

$h_L = 1$ ft

$L_1 = 1$ ft

$L_2 = 5$ ft

$L = 6$ ft

$A = 1.0$ ft^2

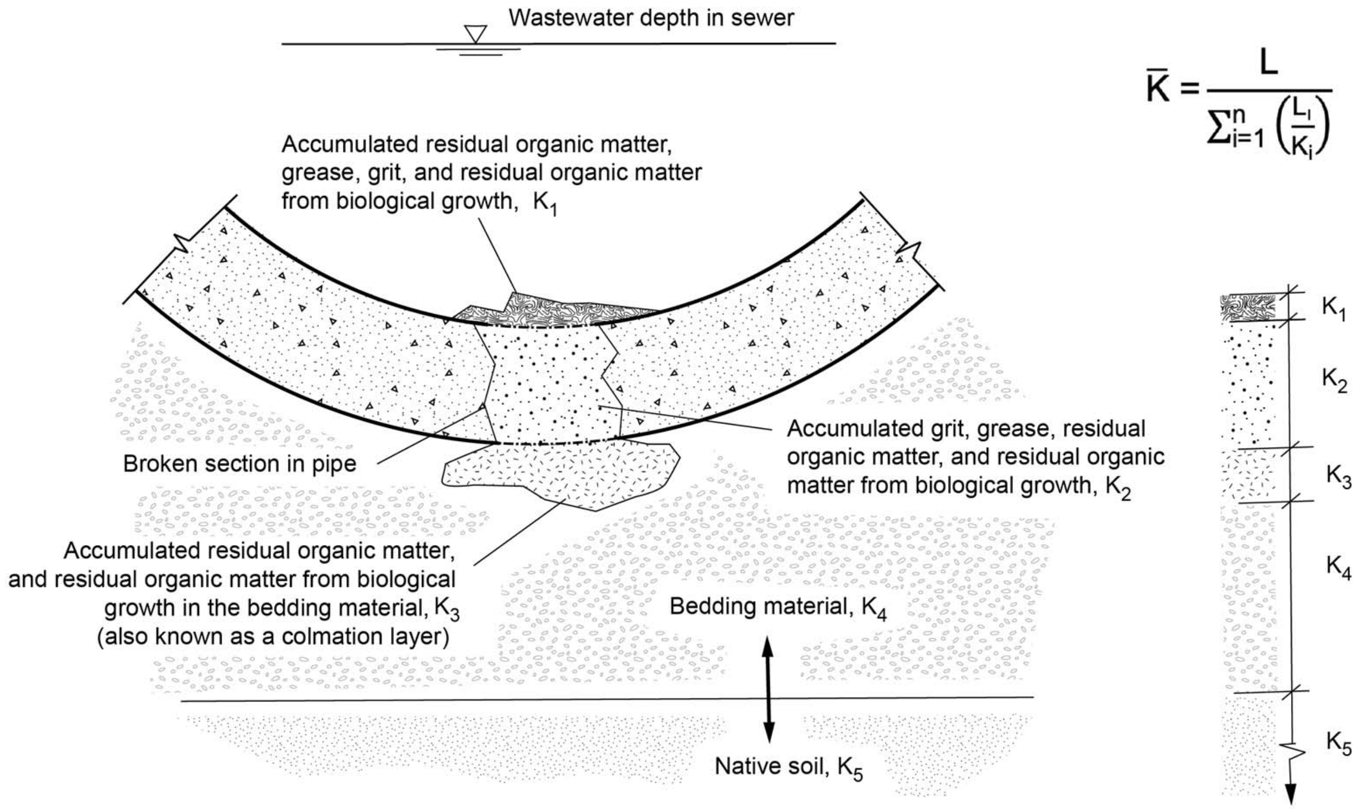
$$\bar{K} = \frac{1 + 5}{\frac{1}{3.25 \times 10^{-4}} + \frac{5}{3.25 \times 10^{-6}}} = 3.89 \times 10^{-6} \text{ ft/s}$$

$$\bar{K} = (3.89 \times 10^{-6} \text{ ft/s}) \times (86{,}400 \text{ s/d}) = 0.34 \text{ ft/d}$$

$$Q = -(0.34 \text{ ft/d})(1 \text{ ft}^2)\,\frac{0 - (6 + 1) \text{ ft}}{(1 + 5) \text{ ft}} = 0.40 \text{ ft}^3\text{/d}$$

$$Q = (0.4 \text{ ft}^3\text{/d})(7.48 \text{ gal/ft}^3) = 3.0 \text{ gal/d}$$

What is the Reality of Estimating Exfiltration: Mission Impossible



$$\bar{K} = \frac{L}{\sum_{i=1}^{n}\left(\frac{L_i}{K_i}\right)}$$

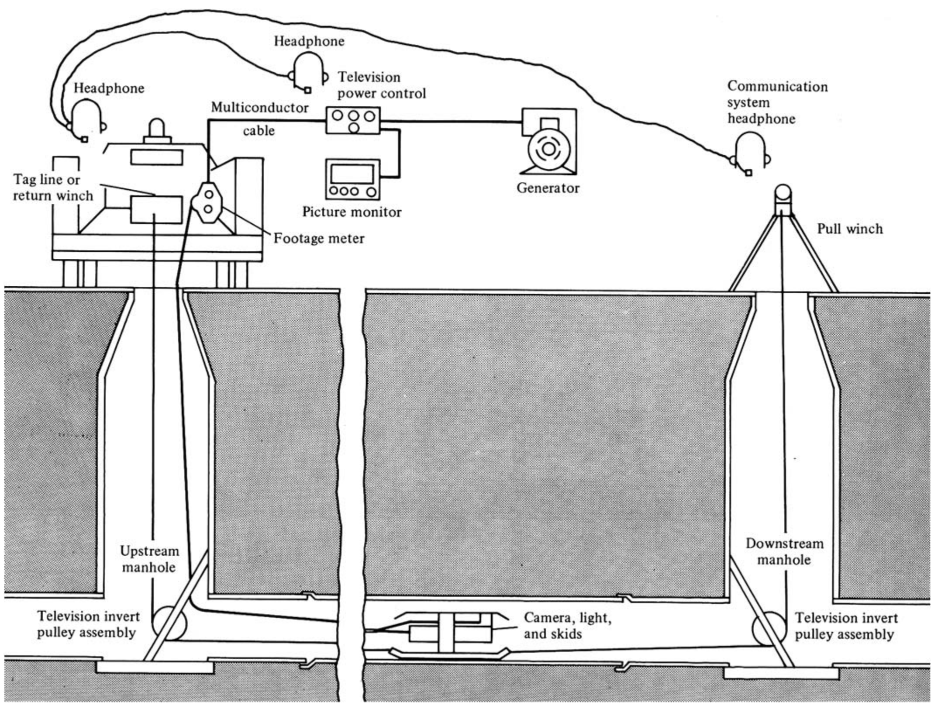
Note: All three types of accumulation contribute to self healing, reducing the extent of exfiltation

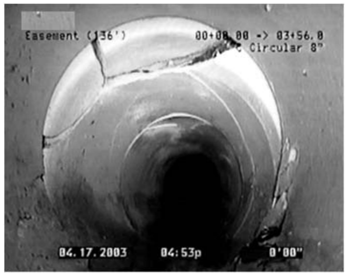
Typical Steps in the Assessment and Maintenance of Wastewater Collection Systems
(Discussed further in Part 3)

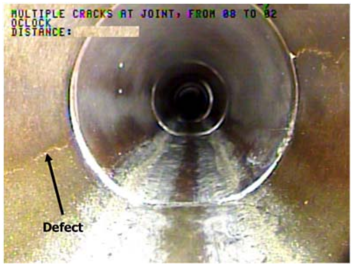
1. Program development
2. Asset inventory (GIS based systems)
3. Asset Assessment/inspection
   a. Selecting and prioritizing assets for inspection (e.g., age, type of pipe material, joint material, external loading, contamination potential, etc.)
   b. Asset inspection
4. Data management
5. Data analysis
6. Decision making
7. Implementation schedule for maintenance

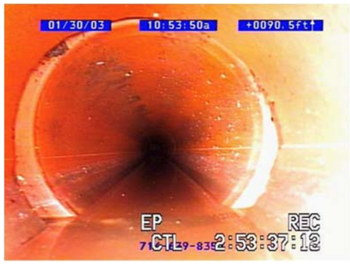
Adapted from US EPA

Typical Setup for Televising A Sewer Between Access Ports (Manholes) to Assess Condition



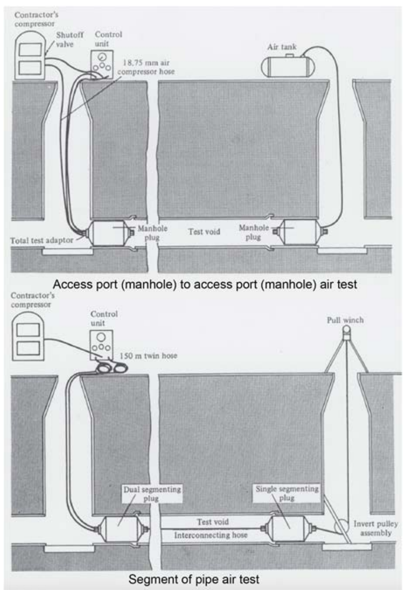


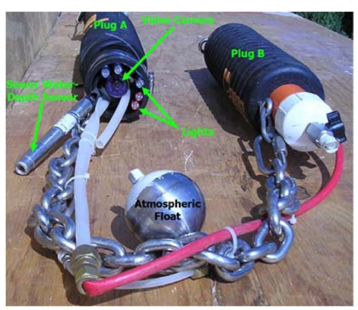




Courtesy: Avami, P., A. Coghill, S. Gifford, and J. Scherfig (2005) *Sewer Exfiltration Test Method for Sub-Subface Discharge Evaluation,* A report prepared for Brown and Caldwell, Project Manager for Orange County Sanitation District, Water Quality and Treatment Laboratory, Civil and Environmental Engineering, University of California, Irvine, CA.

Typical Setup for Exfiltration and Air Testing of Collection Systems



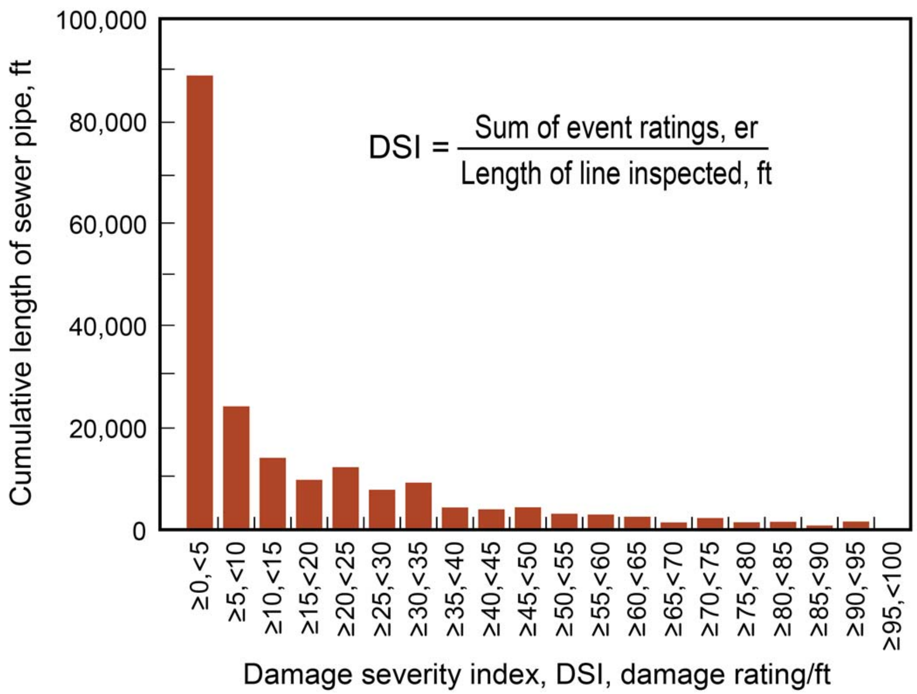


Exfiltration Testing (Avami et al., 2005)

1. Special Exfiltrometer was developed.
2. *Unique feature of "Exfiltrometer* is the ability to control the water level in the test section to any level between one inch water depth and a full pipe."
3. By controlling the depth, the exfiltration test can be conducted at the normal operation depth in the sewer
4. Sewer defects in one OCSD sub-area, based on CCTV:
   - Cracks 483
   - Broken holes 64
   - Roots 374 (increasing with draught conditions)
5. Rates of exfiltration varied from non-detect to 2,100 gal/yr per test location. Considerably lower than those predicted or measured with a conventional exfiltration test (see previous definition)

Avami, P., A. Coghill, S. Gifford, and J. Scherfig (2005) *Sewer Exfiltration Test Method for Sub-Subface Discharge Evaluation,* A report prepared for Brown and Caldwell, Project Manager for Orange County Sanitation District, Water Quality and Treatment Laboratory, Civil and Environmental Engineering, University of California, Irvine, CA.

Use of Damage Severity Index (DSI) for Analyzing Data and Prioritizing Sewer Repairs



Note: DSI is one of many approaches used to analyze CCTV and other sewer system data including contamination potential, pipe material, type of joint, age, etc.

DSI example, based on CCTV assessment

Length of pipe inspected, 200 ft

Event ratings (Sewer problem or condition observed with CCTV)

Broken pipe, longitudinal, er = 500

Roots, difficult or impossible to pass, er = 400

Corrosion, native soil is visible, er = 500

$$DSI = \frac{500 + 400 + 500}{200} = 7.0$$

Courtesy: Stege Sanitary District and Larry Rugaard

Closing Thoughts

1. Exfiltration is a more serious issue in the Western United States, especially with climate change
2. Techniques are available for identifying whether there is a problem
3. To protect and maintain collection systems assets, condition assessment must be an ongoing activity
4. Maintaining a collection system maintenance program is difficult in today's economic environment
5. Be well!

Steve Jepsen

SPEAKER

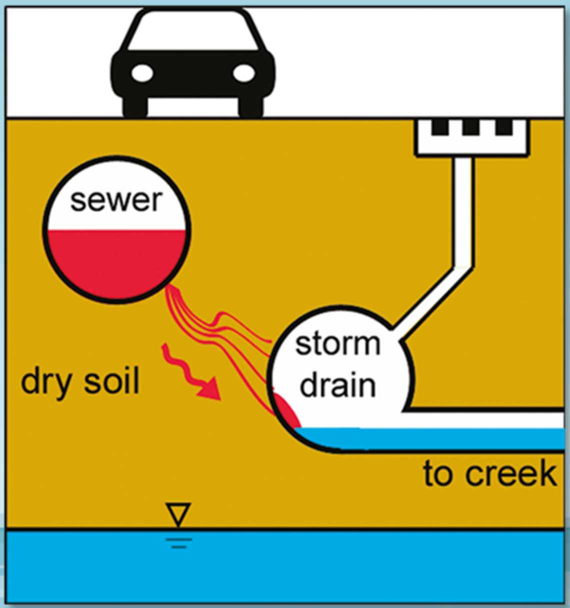
Executive Director, Southern California Alliance of Publicly Owned Treatment Works

SCAP
SOUTHERN CALIFORNIA ALLIANCE OF PUBLICLY OWNED TREATMENT WORKS

CWEA

A Talk About Sewer Exfiltration Theory

and the San Diego Region
"Exfiltration" Investigative Order



(Sercu et al. 2011, ES&T)

August 6, 2020

Steve Jepsen
sjepsen@scap1.org

What Will Be Covered

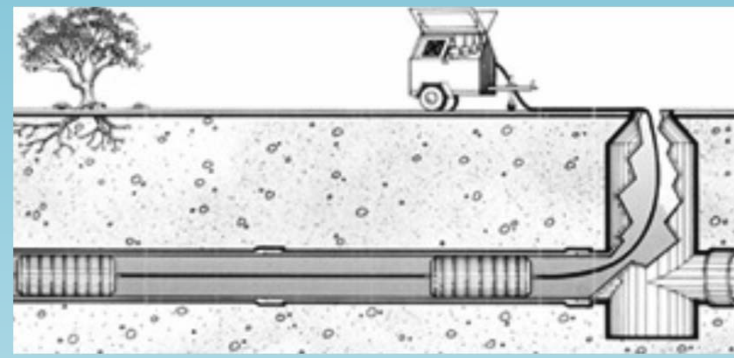
1. What is the problem?
2. The Sewer “Exfiltration” Investigative Order in San Diego
3. Exfiltration theories and investigation approaches
4. Why should we care about exfiltration

What's the Problem?

* Water Quality from Urban Runoff continues to be an issue
* There are little direct funding sources for stormwater quality programs
* Leaking sewer collection systems are considered a likely source by the public, regulators and NGOs despite a lack of evidence

Are Sewers a Bacteria Source? **No?**

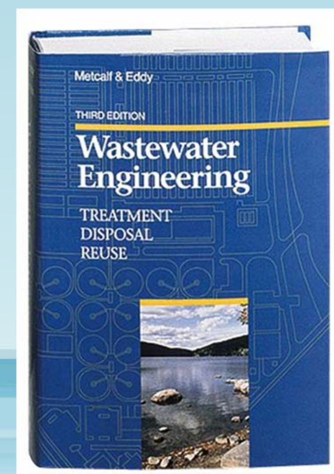
UC Irvine, OCSD, Brown and Caldwell Study 2005 –
Quantifying Sub-surface discharges from Individual Sewer Defects



Metcalf & Eddy Water Treatment Book has a chapter dedicated to how natural treatment systems, in the soil, effectively treat bacteria and viruses

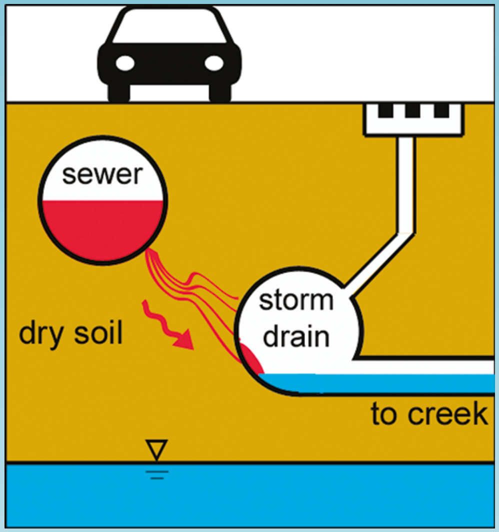
TABLE 14-7
Treatment performance of onsite system components and intermittent or recircu

Parameter	Raw waste (1)	Septic tank effluent (2)	1.0 ft below bottom of leachfield trench (3)	3.0 ft below bottom of leachfield trench (4)
BOD_5, mg/L	210–530	140–200	0	0
SS, mg/L	237–600	50–90	0	0
Nitrogen, mg/L				
Total	35–80	25–60	—	—
NH_4^+	7–40	20–60	20^b	—
NO_3^-	<1	<1	40^b	40^b
Total phosphorus, mg/L	10–27	10–30	10^b	1^b
Fecal coliforms, MPN/100 mL	10^6–10^{10}	10^3–10^6	$^{2}0$–10^2	0
Viruses, PFU/mL[c]	Unknown	10^5–10^7	$^{2}0$–10^3	0



Are Sewers a Bacteria Source? **Yes?**

* City of Santa Barbara Studies
  - Bacteria found in storm drains
  - Dogs used to identify sources
  - Human specific HF 183 tests positive
  - Sewers shown to be a source
  - Dye tests confirm sewer exfiltration into storm drain occurring



(Sercu et al. 2011, ES&T)

San Diego Regional Investigative Order

Investigative Order No. R9-2019-0014 (Adopted June 12, 2019):

An Investigative Order Requiring the Submittal of Technical and Monitoring Reports to Identify and Quantify the Sources and Transport Pathways of Human Fecal Material to the Lower San Diego River Watershed.

- The order directs agencies in the San Diego River Watershed to identify and **quantify** the sources and pathways of human fecal material discharges to the San Diego River and its tributaries.

Here is the Proof?

The order is in response to a Surfer Health Study prepared by SCCWRP and other studies that have identified human fecal matter in the San Diego Watershed

SCCWRP – Surfer Health Study

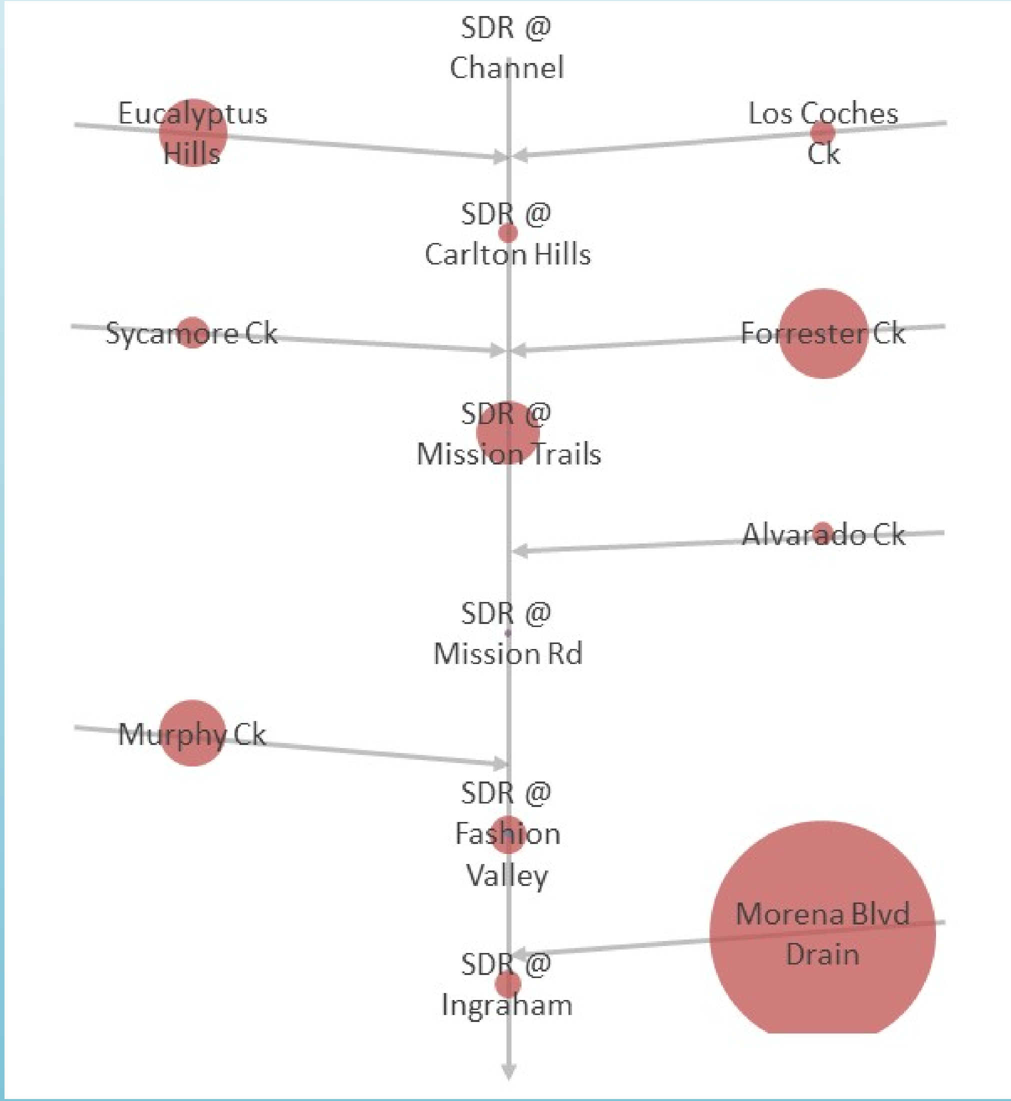
* In the winters of 2013/2014 and 2014/2015, a Surfer Health Study (SHS) was conducted by the Southern California Coastal Water Research Project (SCCWRP), at Ocean Beach and Tourmaline Beach.

* The study measured illness rates of surfers after ocean exposure.

* Results indicated an increased rate of GI illness following ocean exposure compared with not entering the water (25 illnesses/1000 swimmers, vs. 18 illnesses/1000 swimmers). This illness rate increased even further following wet weather (up to 30 illnesses/1000 swimmers).

* USEPA criteria for recreational waters is 32-36 illnesses/1000 swimmers.

Concentrations of Human Marker (HF183) In San Diego River



Storm Date: 1/31-2/1/2016

The San Diego Investigative Order

Footnote in the Order:

12 Exfiltration refers to the leakage of sewage wastewater through minute cracks, gaps or breaks in sanitary sewer collection system infrastructure or private laterals to the surrounding environment. or through the material making up the system itself (e.g. vitrified clay pipe (VCP). For regulatory purposes any sewage exfiltration release from a public sanitary sewer system is defined as a sanitary sewer overflow (SSO) and any sewage exfiltration release from a private lateral is defined as a private lateral sewage discharge (PLSD). Exfiltration may be related to construction practices and/or materials, infrastructure deterioration, inadequate preventive maintenance programs, or insufficient planned system rehabilitation or replacement programs which have resulted in deteriorated pipes, manholes, and pump stations that allow sewage containing high levels of suspended solids, pathogenic organisms, toxic pollutants, nutrients, oil, and grease to exit the systems and contaminate adjacent ground and surface waters, and/or enter the storm drain.

Repeated in the Order:

a. *Exfiltration* - The (agency name here) has not reported to the San Diego Water Board any estimation regarding the exfiltration of wastewater from the sanitary sewer collection system to the Lower San Diego River Watershed.

The San Diego Investigative Order Requires

The ten agencies in the watershed shall:

* Identify and quantify relative contributions of suspected sources of human fecal material in wet weather discharges to the San Diego River

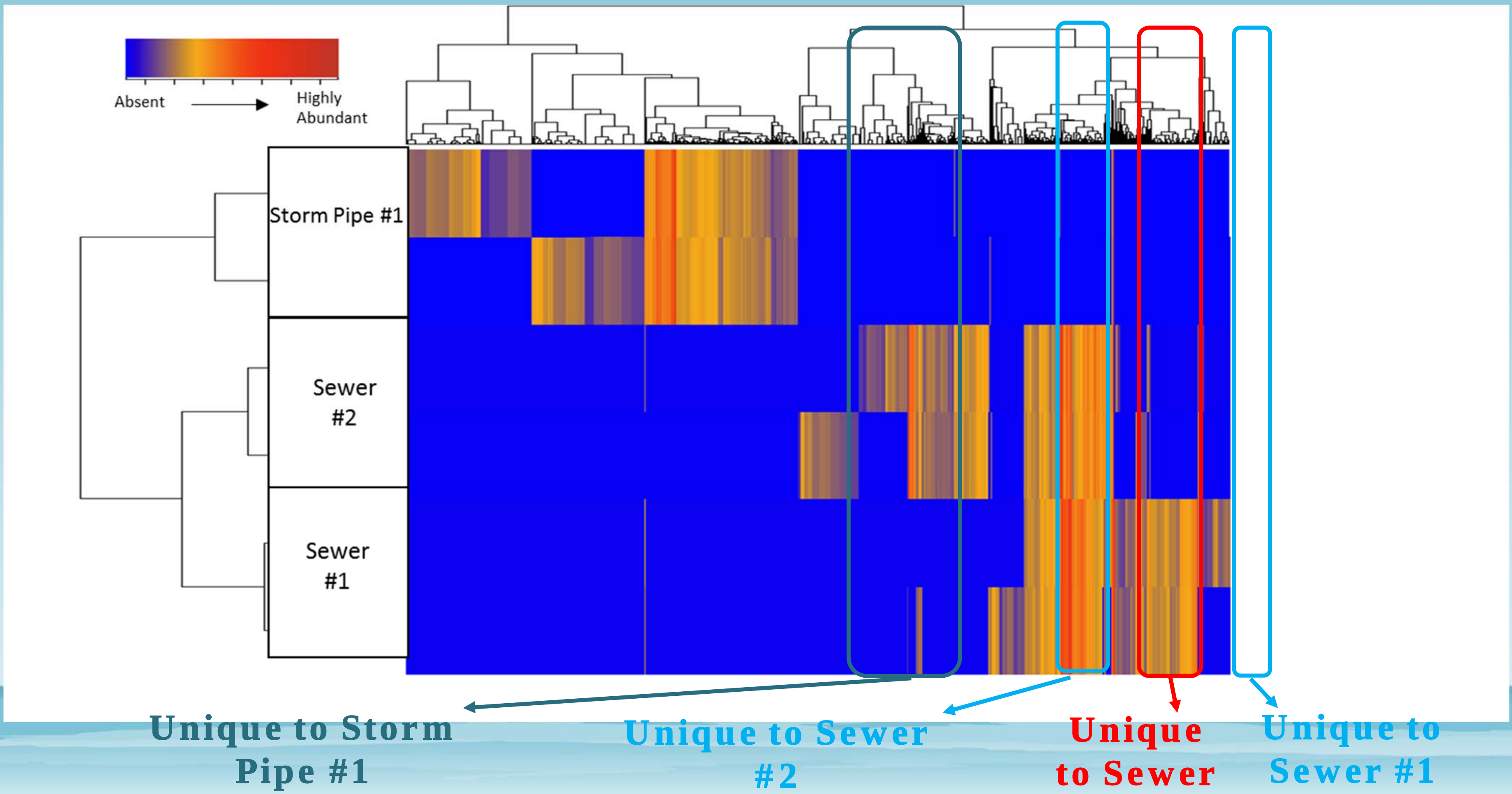
* Determine the transport pathways of such discharges

* Determine how this information will be used by each Discharger to assess the effectiveness of current management measures in preventing discharges of human fecal matter into the San Diego River

SCCWRP Work Plan Tasks

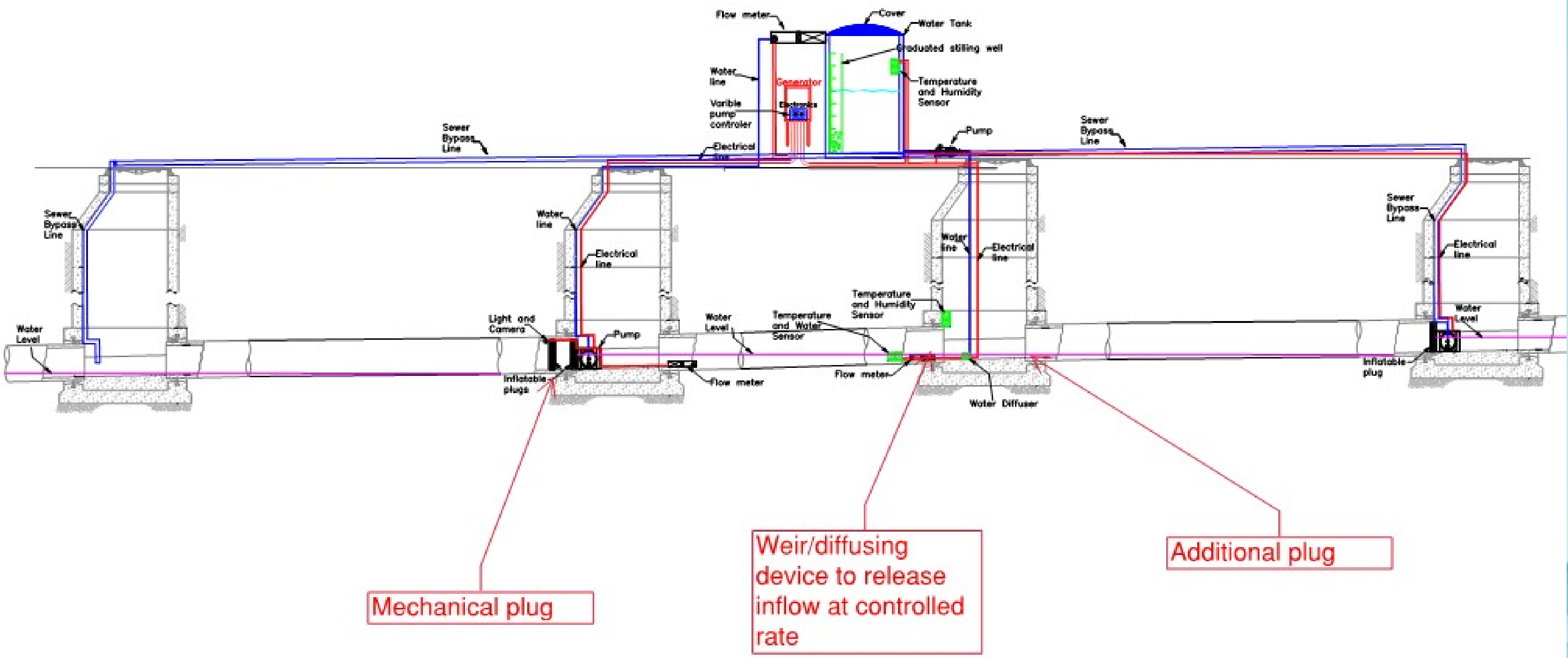
1. **Steering Committee and Technical Advisory Committee**
2. **GIS Foundation**
3. Human Fecal Contamination from **Exfiltration of Publicly Owned Collection Systems**
    - **Microbial Community Profiling**
4. Human Fecal Contamination from **Exfiltration of Private Laterals**
5. Human Fecal Contamination from **Homeless Encampments**
6. Human Fecal Contamination from **Septic Systems**
7. Human Fecal Contamination from **Dry Weather Illicit Connections/Illicit Discharge**
8. **Frequency and Magnitude of Sanitary Sewer Overflows**
9. **Reporting and Data Management**

Microbial Community Profiling

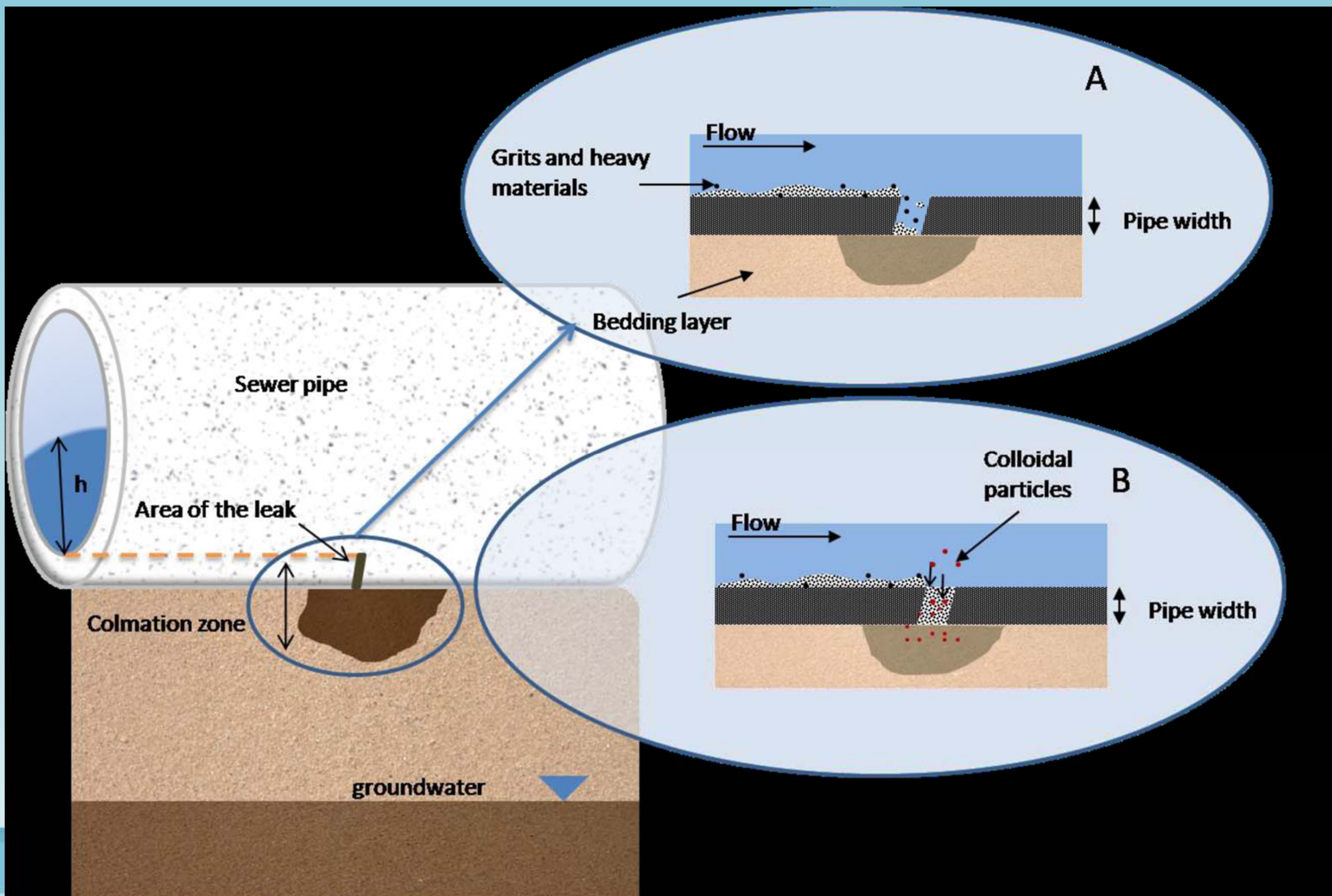


Exfiltration Measurement Device

Need to review pipe test segments for laterals & slope of pipe.
Volume of water required for test is a concern, variables include size, slope, length.
Test segment should not have laterals.

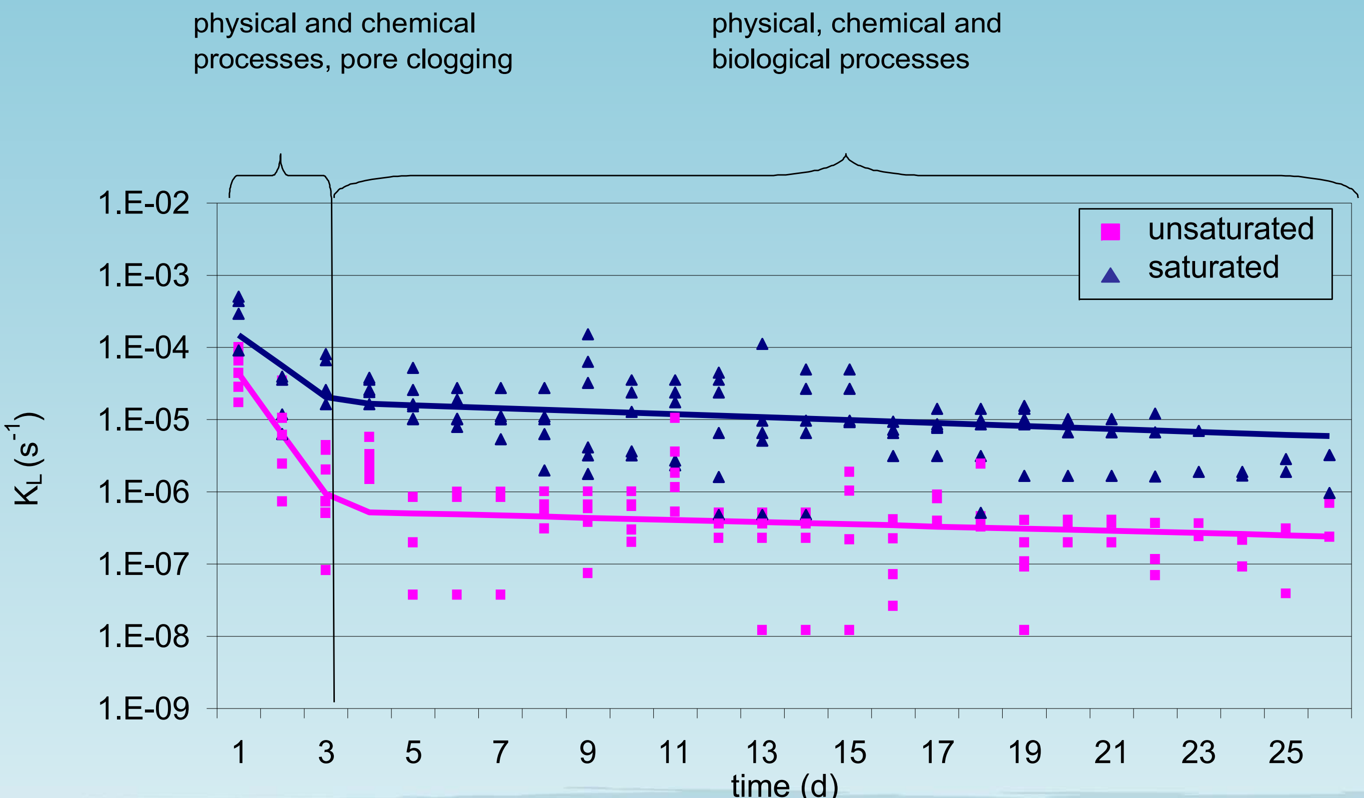


Colmation Layer



- Colmation Layer (clogging layer)
- Accumulation of suspended solids and biomass
  - 1 to 5 cm thick
  - Reduces K and porosity
  - Exfiltration decreased or eliminated
- Referenced in several publications:
  - UK study
  - German study
  - OCSD/UC Irvine study

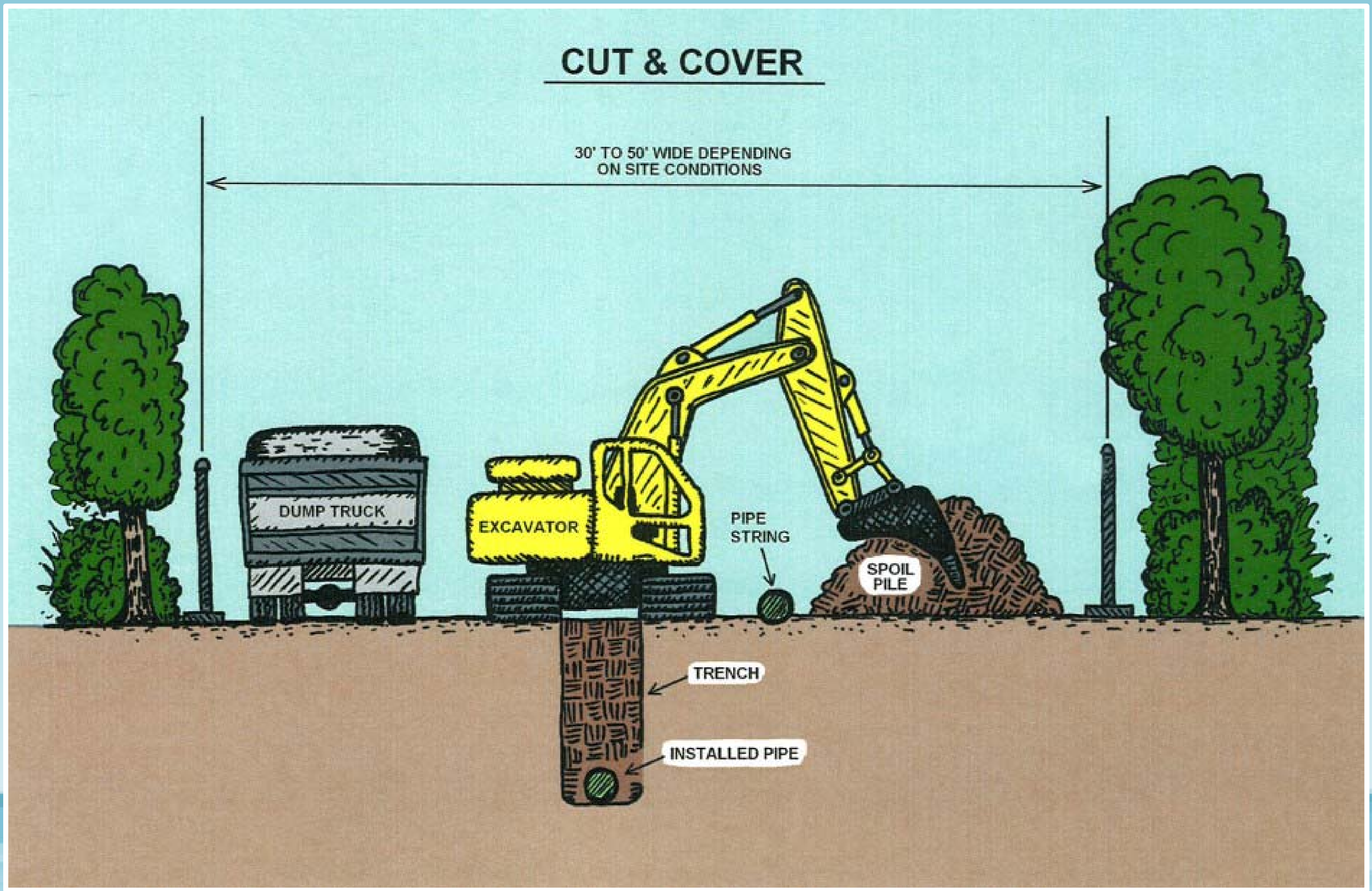
Colmation Layer



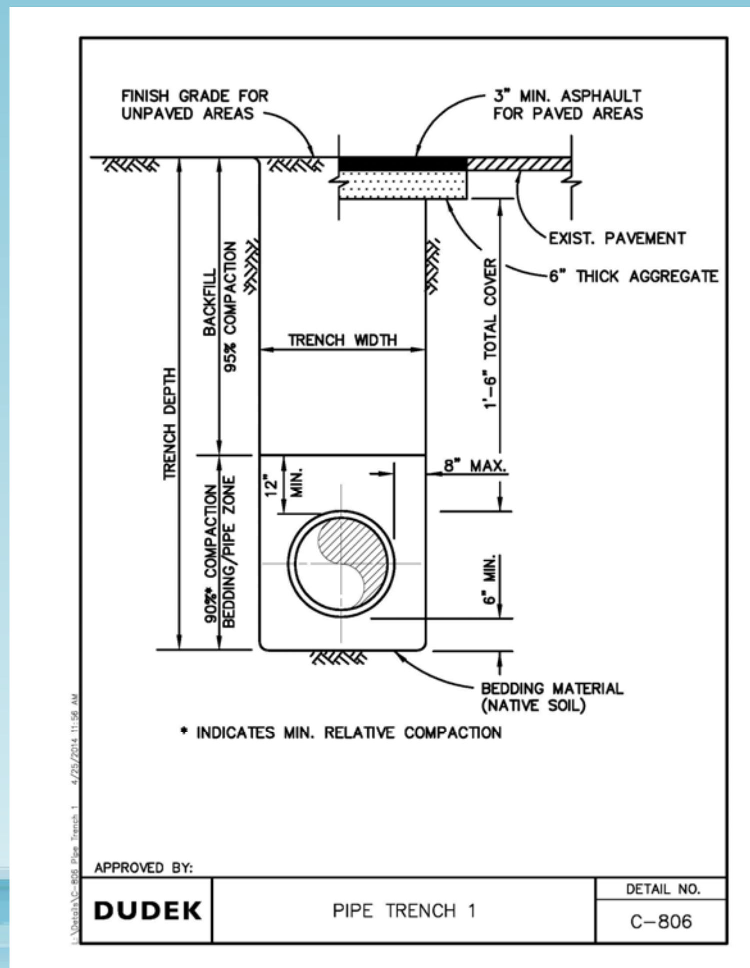
Exfiltration and formation of colmation layer

- Study related K_L to capillary pressure and colmation layer
  - As colmation layer develops, decrease in K_L
    - 1 to 2 orders magnitude in 3 days

Sewer Construction

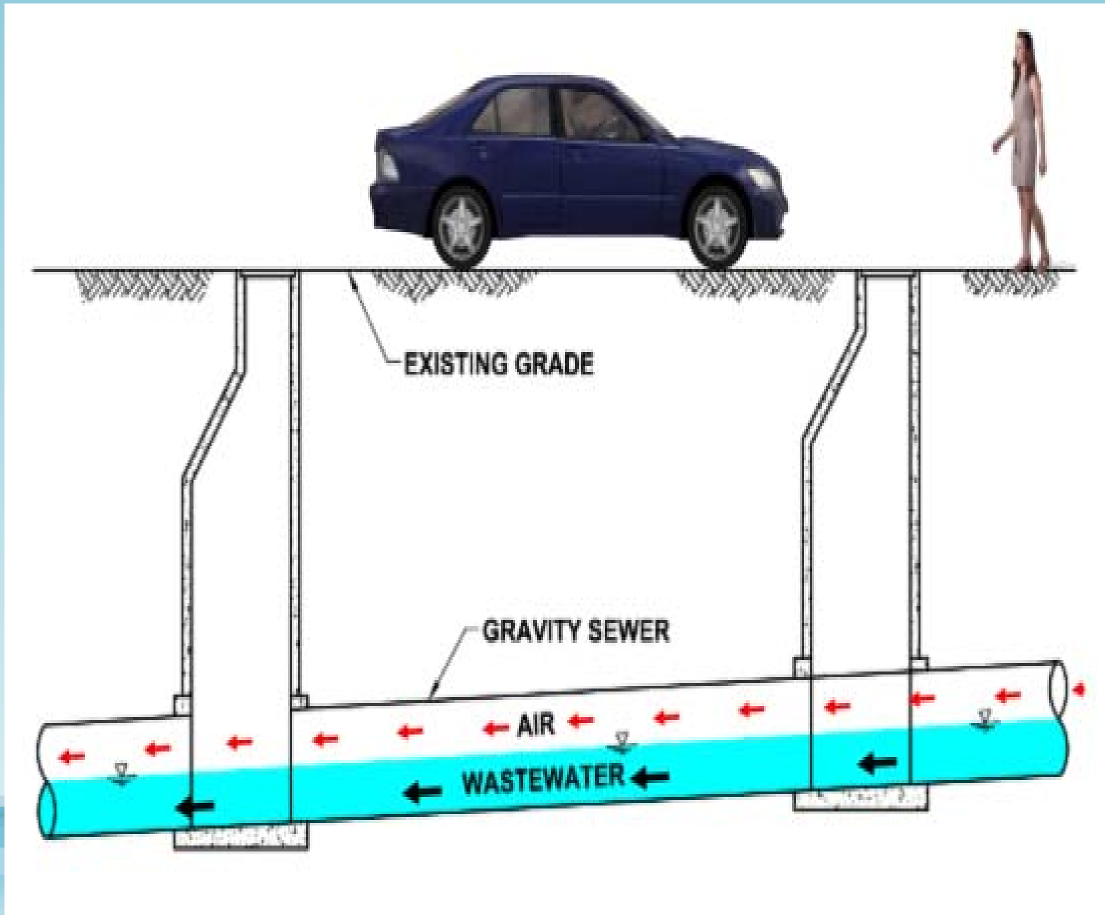


Trench Bottom and Pipe Zone

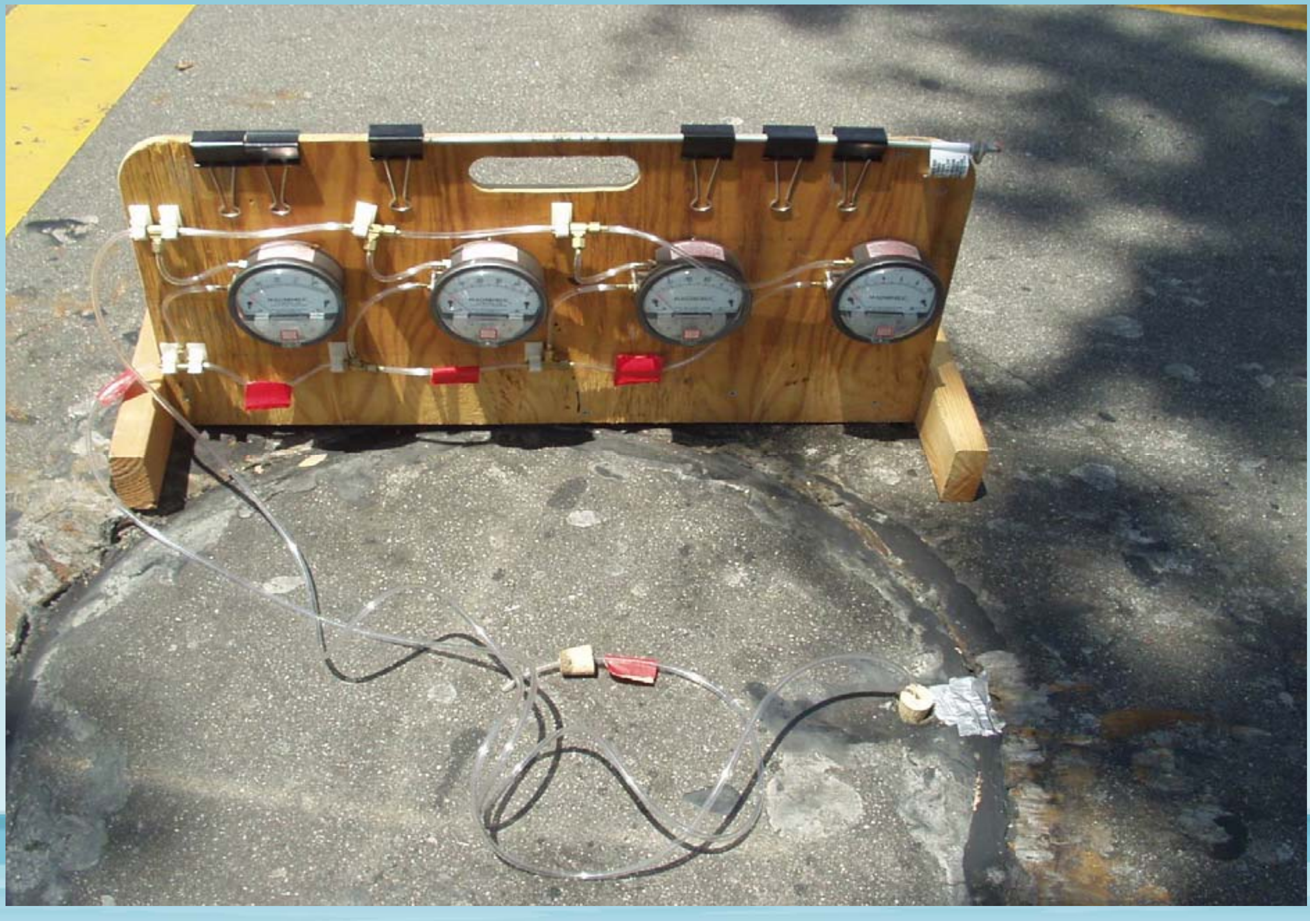


Normal Open Channel Sewer – Headspace Air Travels with Sewage

- Sewers Flow Partially Full
- “Headspace” = Air Above Water Surface
- “Headspace” Conducts Foul Air
- Creating Negative Pressure

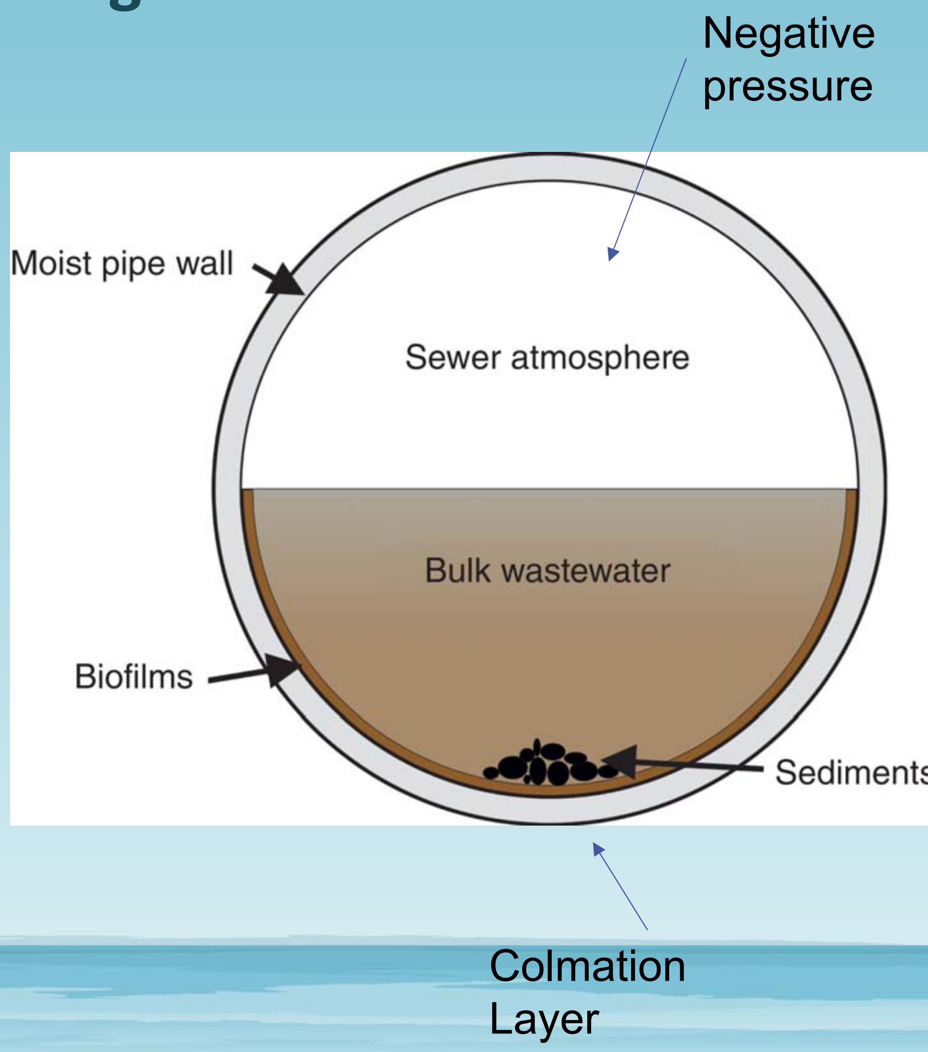


Dwyer Instruments – Magnehelic Pressure and Vacuum Gauges



Conditions Preventing Exfiltration

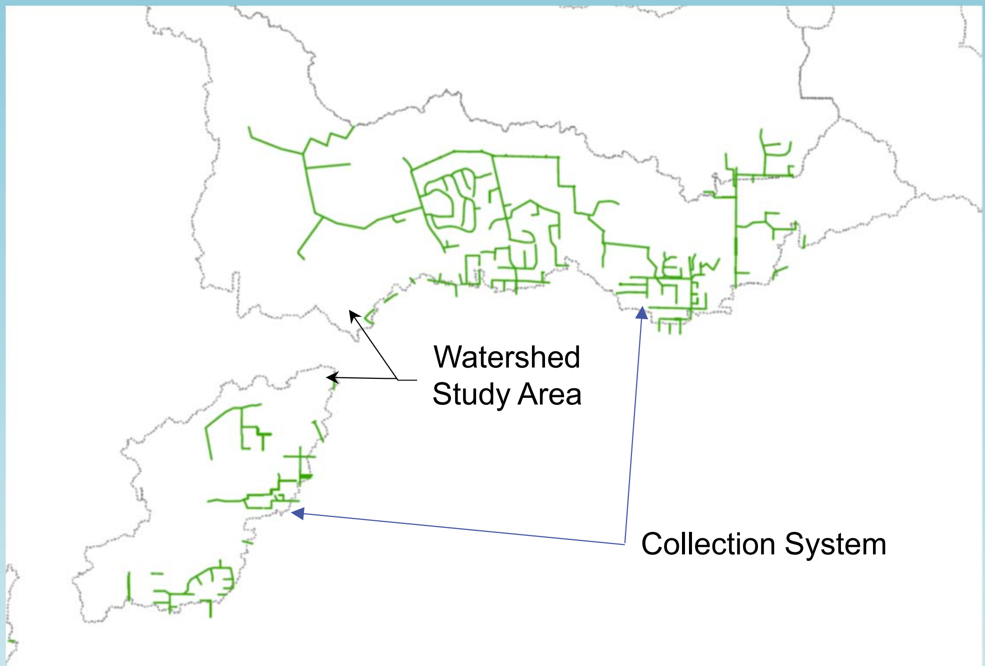
- Colmation layer
- Gravity sewer at zero or negative pressure
- Half full is maximum design flow
- Normal peak flow is less than half full
- Diurnal flow patterns create daily low flow periods far below half full
- High groundwater creates positive pressure into pipe favoring infiltration
- Compacted trench bottom not conducive to percolation
- Declining flow = higher grease and suspended solids content
- Modern joints and pipe materials
- Effective natural treatment occurs in soil
- Finally the sewage must push through soil and through the stormdrain pipe




Storm and Sewer Infrastructure &
GIS Data
POLL
QUESTION
CWEA

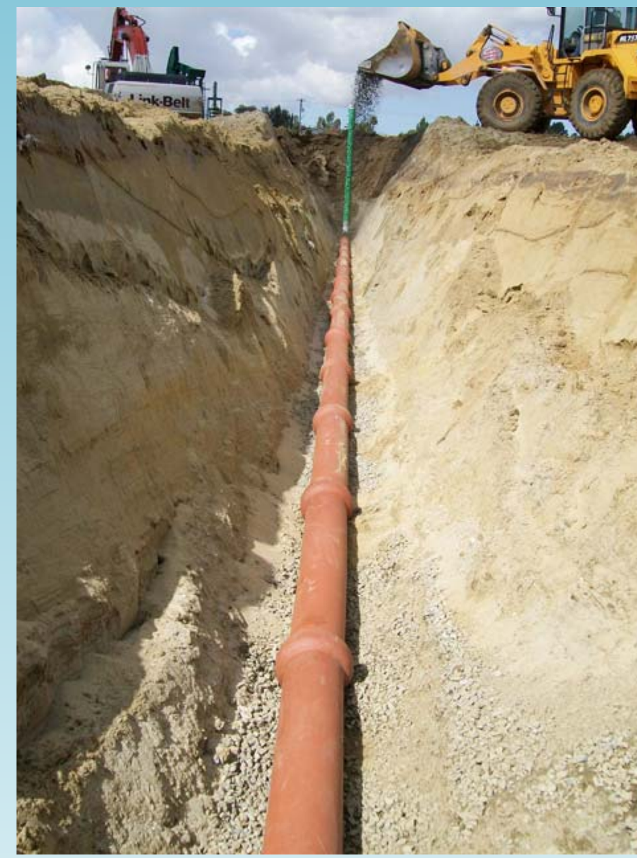
Desktop GIS Approach

- 507 pipes
- 93,000 ft (18 miles)



Desktop GIS Investigation

- Contributing Factors
  - Pipe Crossings
  - Vertical Separation
  - Sewer Pipe Material/Age/Condition
  - Sewer Flow
  - Storm Drain Material/Age
  - Soil Type



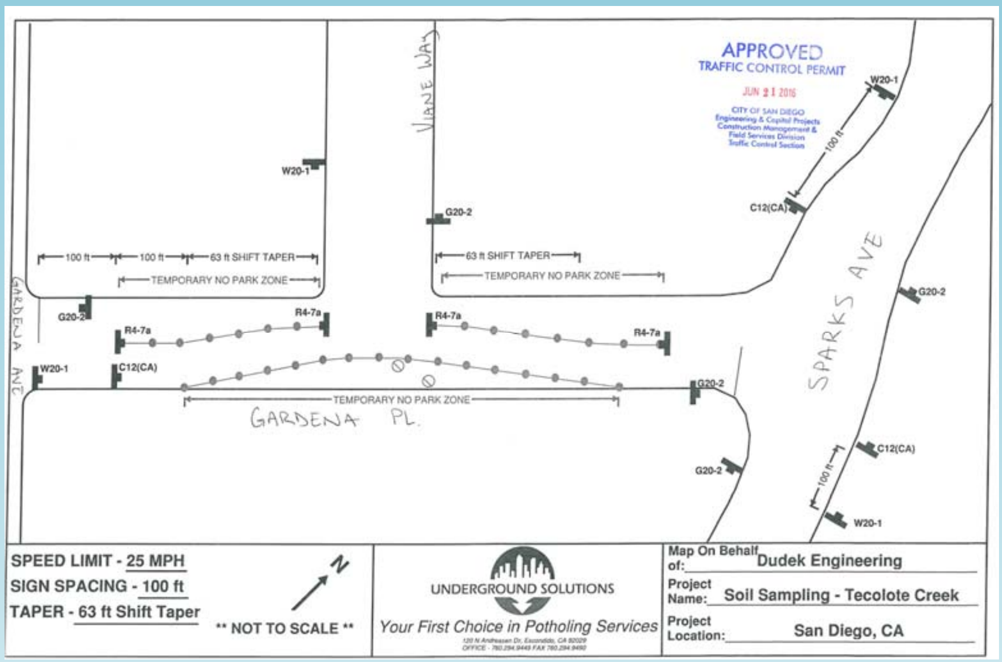
Desktop GIS Priority Ratings

- Scoring matrix-based
  - 19 of 507 (4%) sewer pipe segments above storm drain
  - 12 of 19 (2%) also cross storm drain
  - 6 of 12 (1%) also have defect
  - 2 of 6 (0.3%) also in sandy soil → highest rating

Site ID	Spatial Relationship				Ground Water					Sewer Pipe Priority Rating					Storm Drain Pipe Priority Rating					Soil Priority Rating			FINAL SCORE	Rank
	Vert. Dist.	Horz. Dist	Avg	Total	In Valley?	Swr Depth	Vert. Dist.	Avg	Total	Flow Depth	Defect	EMA	Avg	Total	SD Mat'l	Size	Age	Avg	Total	Perm. (in/hr)	Avg	Total		
116	5	1	3.0	**9.0**	3	3	5	3.7	**3.7**	1	0	0	0.3	**1.7**	2	3	2	2.3	**2.3**	3	3.0	**6.0**	22.7	8
176	5	3	4.0	**12.0**	3	2	5	3.3	**3.3**	2	2	0	1.3	**6.7**	2	5	2	3.0	**3.0**	1	1.0	**2.0**	27.0	3
223	5	3	4.0	**12.0**	3	1	5	3.0	**3.0**	1	0	0	0.3	**1.7**	2	5	2	3.0	**3.0**	1	1.0	**2.0**	21.7	10
225	5	2	3.5	**10.5**	3	2	5	3.3	**3.3**	2	0	0	0.7	**3.3**	2	5	2	3.0	**3.0**	1	1.0	**2.0**	22.2	9
257	4	3	3.5	**10.5**	3	1	5	3.0	**3.0**	1	2	0	1.0	**5.0**	3	3	2	2.7	**2.7**	1	1.0	**2.0**	23.2	7
277	5	3	4.0	**12.0**	3	1	5	3.0	**3.0**	1	2	0	1.0	**5.0**	2	3	2	2.3	**2.3**	1	1.0	**2.0**	24.3	5
302	5	3	4.0	**12.0**	1	1	5	2.3	**2.3**	0	3	0	1.0	**5.0**	2	2	2	2.0	**2.0**	1	1.0	**2.0**	23.3	6
333	5	3	4.0	**12.0**	3	2	5	3.3	**3.3**	2	4	0	2.0	**10.0**	3	4	3	3.3	**3.3**	3	3.0	**6.0**	34.7	1
368	5	1	3.0	**9.0**	3	2	5	3.3	**3.3**	1	4	0	1.7	**8.3**	4	1	3	2.7	**2.7**	1	1.0	**2.0**	25.3	4
590	4	3	3.5	**10.5**	1	1	5	2.3	**2.3**	1	3	1	1.7	**8.3**	3	2	2	2.3	**2.3**	3	3.0	**6.0**	29.5	2

Field-based Approach

Field-based Approach Preparation



Traffic Control Plan

Water Pollution Control Plan

Field-based Approach

Air Knife Technology

Excavated Hole (to pipe bedding)

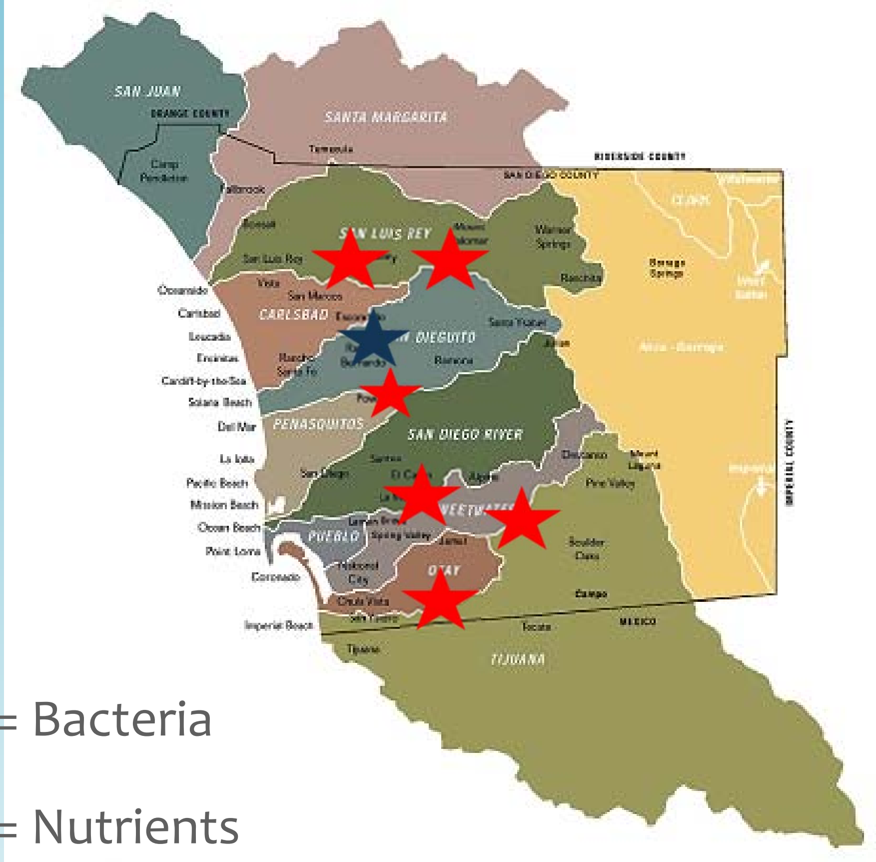
Field-based Approach

Direct Push Rig

Processing

Sample Collection

What are the Drivers?



★ Priority = Bacteria

★ Priority = Nutrients

San Diego Region

- WQIP Strategies
  - Page 557 of 1,368

ID	Strategy	Implementation Approach (Frequency of Inspections, B.3.b.(1)(a)(iv)) (Funds/Resources, B.3.b.(1)(b)(iv), B.3.b.(3)(a)(iii)) (Triggers, B.3.b.(1)(b)(v)) (Inventory BMPs, B.3.b.(1)(a)(ii))	Jurisdictional (B.3.b.(1)(a)) or Optional (B.3.b.(1)(b))	Implementation or Construction Year (B.3.b.(3)(a)(i); B.3.b.(3)(a)(ii))	Implementation Schedule (B.3.b.(3)(a)(iv))	Pollutants Addressed							Source (B.3.b(1)(a)(i))	Responsible City Department and Other Collaborating Departments or Agencies (B.3.b.(1)(c))
						Bacteria	Nutrients	Metals	Trash	Sediment	Flow	Habitat/ Wildlife		
MS4 Infrastructure														
DAM-12	Implementation of operation and maintenance activities (inspection and cleaning) for MS4 and related structures (catch basins, storm drain inlets, detention basins, etc.).	Refer to JRMP Section 7. The MS4 inventory is inspected by Public Works staff at least once per year. Based on the findings of the inspections, the City performs required cleanings and proper disposal of collected material. Removal of the collected trash and debris prevents the materials from being pushed through the system and into the receiving waters from runoff	Jurisdictional	FY16	Continuous-Ongoing	X		X	X	X			MS4	Public Works and Clean Water Program
DM-12.1	Perform catch basin cleaning	Inspect and clean catch basins annually	Jurisdictional	FY16	Continuous-Ongoing	X	X	X		X			MS4	Public Works and Clean Water Program
DM-12.2	Repair and replace MS4 components as needed to provide source control from MS4 infrastructure.	In order to limit inflow of pollutants and reduce pollutant loads, the City will take proactive measures to improve, repair, and replace MS4 components.	Jurisdictional	FY16	Continuous-Ongoing	X	X	X		X			MS4	Public Works and Clean Water Program
DM-13	Implement controls to prevent infiltration of sewage into the MS4 from leaking sanitary sewers and identify sewer leaks and areas for sewer pipe replacement.	Refer to JRMP Section 4.7 and the City's Sanitary Sewer Management Plan. The conducts a variety of activities to effectively operate, maintain, repair and replace sewer mains, manholes, and pump stations.	Jurisdictional	FY15	Continuous-Ongoing	X							MS4	Public Works and Clean Water Program

"Implement controls to prevent infiltration of sewage into the MS4 from leaking sanitary sewers and identify sewer leaks and areas for sewer pipe replacement."

Los Angeles

- LA River eWMP Strategies
  - Page 92 of 694

#	WCM Category/ID	WCM	BMP effectiveness with respect to WQPs					Agency								
			Category I	Category II	Category III	Sediment reduction	Volume or flow reduction	Downey	Flood Control	Lakewood	Long Beach	Lynwood	Paramount	Pico Rivera	Signal Hill	South Gate
15	MCM-PIP-1	Stormwater resources on City website	◈	◈	◈	◈	◈	✗	✗	✗	✗	✗	--	✗	✗	✗
		Public Agency Activities														
16	MCM-PAA-1	Enhanced BMP requirements for fixed facility/field activities	◈	◈	◈	◈	◈	✗	✗	✗	✗	✗	--	✗	✗	✗
17	MCM-PAA-2	Reprioritization of catch basins and clean-out frequencies	◆	◆	◆	◆	◇	✗	✗	✗	✗	✗	--	✗	✗	✗
18	MCM-PAA-3	Integrated Pest Management Program	◈	◈	◈	◇	◇	✗	✗	✗	✗	✗	--	✗	✗	✗
19	MCM-PAA-4	Enhanced measures to control infiltration from sanitary sewers	◆	◆	◇	◇	◇	✗	✗	✗	✗	✗	--	✗	✗	✗

"Enhanced measures to control infiltration from sanitary sewers"

California City Liable for Contamination Spread by Leaky Sewers

Posted Feb. 6, 2019, 11:04 AM
By Peter Hayes

- 'Defects' in sewers spread contamination
- City splits cleanup costs with dry cleaner

The city of Visalia, Calif., is on the hook for half of all future Superfund cleanup costs for contamination that originated from a dry-cleaning business spread because of the city's poorly maintained sewer system, the Eastern District of California ruled.

While the contamination originated on a commercial laundry facility operated by Mission Linen Supply, the city contributed to the releases of perchloroethylene and other hazardous substances from its sewer system, the court said.

The sewers have numerous "defects," including holes, broken pipes, exposed soil, cracks, sags, separated joints, missing portions of pipe, root intrusion, debris, and blockages, the court said.

The contamination spread to ground water and contaminated drinking water wells, the court said.

In 2010, the California Department of Toxic Substances Control ordered Mission Linen to conduct environmental studies and cooperate in cleanup efforts.

Mission Linen in May 2015 filed a Superfund contribution claim against the city.

The court held a bench trial to allocate liability between the city and Mission Linen. Following the trial, the parties engaged in settlement talks for more than a year, but failed to reach a resolution.

Mission Linen and the city will evenly split all future response costs incurred by Mission related to the PCE plume, the court ruled.

The city is responsible for 100 percent of any repairs to the sewers that may be necessary.

Judge Anthony W. Ishii issued the ruling.

Greben & Associates represented Mission Linen Supply.

Herr Pedersen & Berglund, LLP and Wood Smith Henning & Berman LLP represented the city.

The case is Mission Linen Supply v. City of Visalia, 2019 BL 37490, E.D. Cal., No. 15-CV-0672, 2/5/19

Conclusions

* Bacteria are a frequent constituent of concern in watersheds
* Stormwater quality practitioners and scientists don't always understand collection systems
* Sewer Exfiltration to MS4 Infiltration is a prime suspect, there are rare but documented cases were it has occurred
* Sometimes there is a rush to judgement based on a lack of understanding of collection system operation/construction
* We need to get out in front of this issue and:
  * Educate the public, regulators and stormwater quality practitioners
  * Design focused exfiltration investigation and remediation practices for our collection systems


Q&A
CWEA

Conclusion – What Can an Agency Do to be Proactive?

Things an Agency Can Do to be Proactive

1. Get educated and prepare for conversations
   - Understand how exfiltration happens and where it might be an issue
   - Understand local and regional regulatory issues pertaining to exfiltration

2. Build collaborative relationship with stormwater agencies in areas you serve
   - Communicate information needs to support risk assessment (i.e. stormwater system mapping)

Things an Agency Can Do to be Proactive

3. Identify which pipe segments might have impacts

- Close proximity to:
  - surface water body or drainage channel
  - lower elevation unprotected stormwater pipe
- Over shallow groundwater basin with beneficial uses and without adequate distance for soil treatment
- Pipes conveying industrial waste streams

Things an Agency Can Do to be Proactive

4. Assess condition of pipes in locations with potential impact
   - Identify defects having leakage potential

5. Address defects with potential impact
   - Repair plans or 5-year/10-year capital improvement plans

Sample video images of sewer lines showing broke pipe, partial collapses, offset joints & intruding laterals.

Contact Hours

Live webinar participants who participate in the full webinar to see the slides and hear the audio will receive contact hours. Your contact hour certificate can be viewed on your mycwea.org account in 1-2 weeks.

Further instructions for accessing your certificate can be found here.

CWEA

Thank You!

Please complete the participant survey:
www.surveymonkey.com/r/sewer8620