Engineer Manual: 1110-2-1914 Design, Construction, and Maintenance of Relief Wells *REVIEW UPDATE*

Mike Navin, Ph.D., P.E.

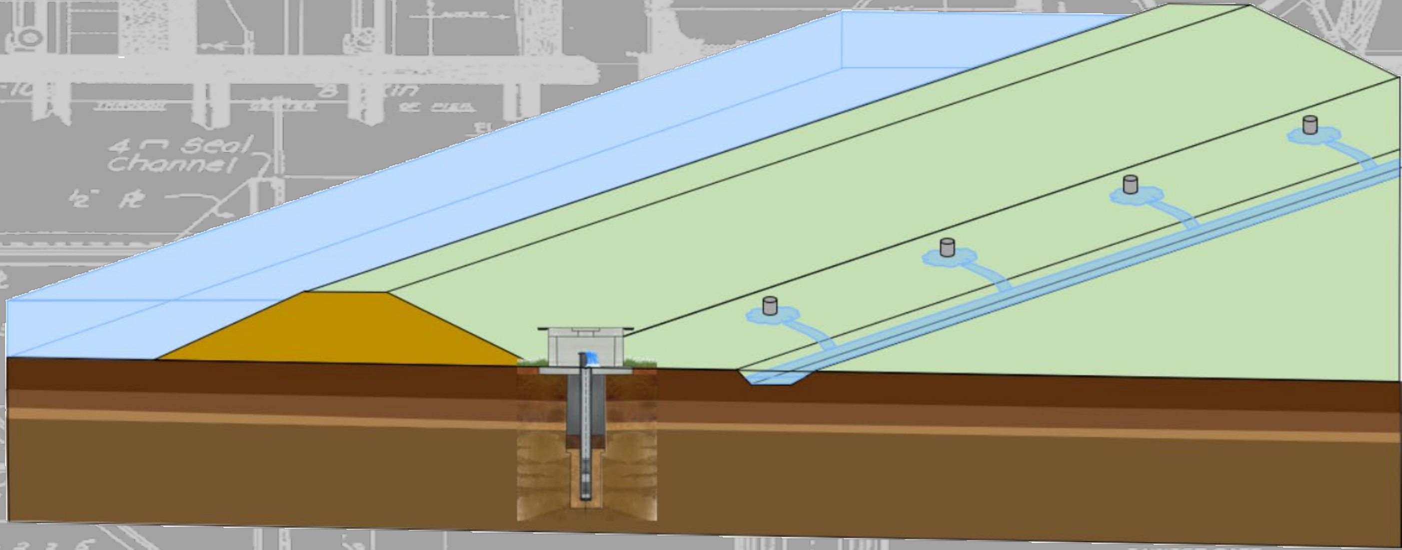
Levee Safety Center (MVS)

Erich Guy, Ph.D., P.G.

Huntington District (LRH)

Glen Bellew, P.E.

Levee Safety Program Manager (NWD)



US Army Corps of Engineers

U.S. ARMY

LSC LEVEE SAFETY CENTER

CONTRIBUTORS TO EM UPDATE

Primary Authors:

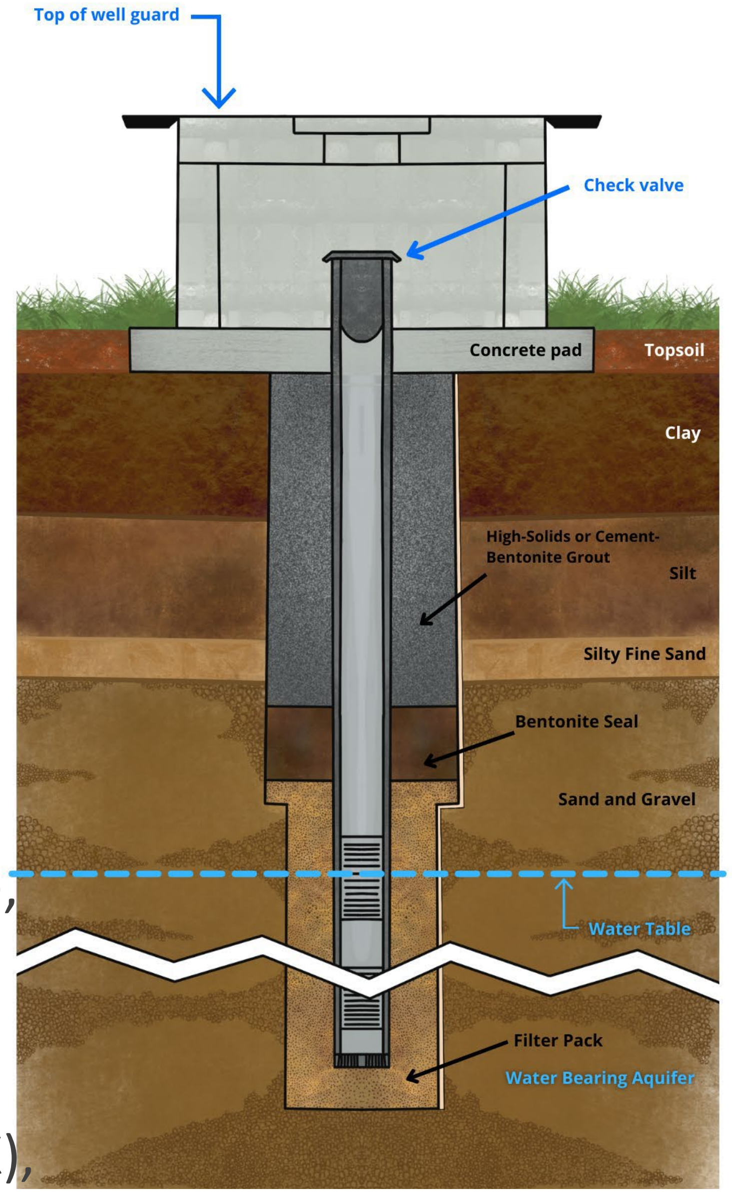
Mike Navin (LSC), Patrick Conroy (LSC), Glen Bellew (NWD), Erich Guy (LRH), Andrew Keffer (LRH), Bill Niemann (LRH), Lizzy Chang (LRH), Kenneth Darko-Kagya (SWG), Stefan Flynn (MVR), Tricia North (NAP), Thom Davidson (RMC)

Other Contributors:

Noah Vroman (LSC), Joe Dunbar (ERDC), Lucas Walshire (ERDC), Sofia Boscio-Lopez (LRH), Lisa Gatens (LRH), Kristen Paul (NAE), Seth Weidner (MVS), Khaled Chowdhury (SPD), Brenda Adams (NWK), Cathy Fox (MVS), Kathy Older (NWK)

Reviewers:

John "Ben" Tatum (MVM), Coleman Chalup (POA), Jacob Owen (NWK), Jason Wager (NWO), in addition to review of 2017 content from Scott Shewbridge (IWR), Scott Vollink (NWD), Richard Hockett (LRL)

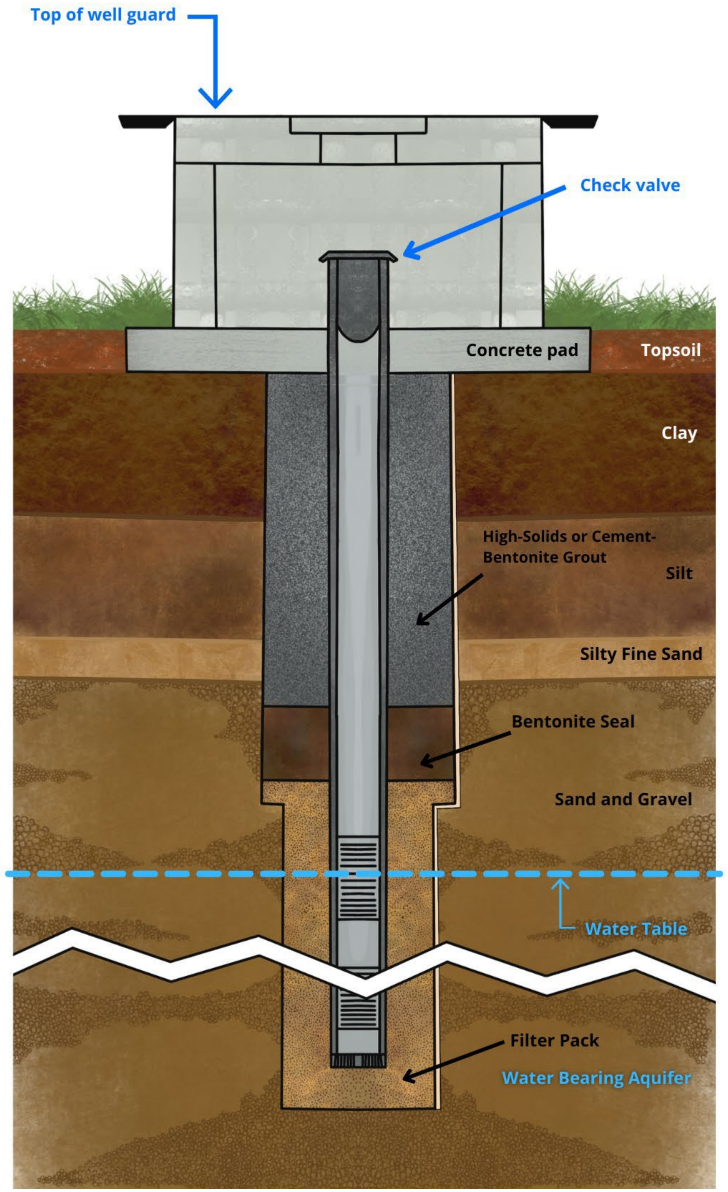


US Army Corps of Engineers

U.S.ARMY

AGENDA

- Overview of Chapters and Appendices
- Overall Schedule
- Manual Update Highlights
- What you should know
- Q&A



US Army Corps of Engineers

U.S.ARMY

CHAPTERS -

Chapter 1: Introduction

Chapter 2: Relief Well History and Applications

Chapter 3: General Well System Design Considerations

Chapter 4: Risk Considerations

Chapter 5: Analysis and Design of an Infinite Line of Wells

Chapter 6: Analysis and Design of a Finite Line of Wells

Chapter 7: Design of Well and Screen

Chapter 8: Relief Well Installation

Chapter 9: Relief Well Pumping Test, Efficiency, and Well Head Loss

Chapter 10: Relief Well Collector Systems

Chapter 11: Operation and Maintenance for Well Systems (inspection, testing, rehabilitation)

US Army Corps of Engineers

U.S.ARMY

CHAPTER 1 - INTRODUCTION

- Purpose of Manual – EM 1110-2-1914 covers the design, construction, and maintenance of relief wells at dams, levees, and navigation structures

- Purpose of Relief Wells – Relief wells are designed to reduce foundation pressures while preventing the movement of foundation materials. The controlled release of seepage prevents the buildup of pressures which might otherwise endanger the stability of the feature.

- Layout of Manual

US Army Corps of Engineers

U.S. ARMY

CHAPTER 2 - RELIEF WELL HISTORY AND APPLICATIONS

- May 29, 1992 – EM 1110-2-1914 Issued
- Based on Waterways Experiment Station (WES) research that started in 1940's and 1950's
  - Conference and ECB (1955)
  - TM 3-424 and TM 3-430 (1956)

History is Important Because;

(1) many concepts are retained but the analysis tools have changed,
(2) legacy well systems are still in operation

US Army Corps of Engineers

U.S. ARMY

WHAT’S CHANGED IN 30 YEARS?

- Science and Engineering Practice Expanded
- 30 More Years of Performance Observations
- Evolution of USACE Dam and Levee Safety Programs
- Risk Assessments for Evaluation and Design
- Subsurface Collection more Common

US Army Corps of Engineers

U.S. ARMY

CHAPTER 3 - GENERAL WELL SYSTEM DESIGN CONSIDERATIONS

- Relief Well Application
- Collection of Relief Well Discharge
- Seepage Analysis
- Site Characterization
- Relief Well Penetration
- Performance Monitoring

Figure 3.3. Example of sand boil, East St. Louis, 2016 New Year’s Day Flood.

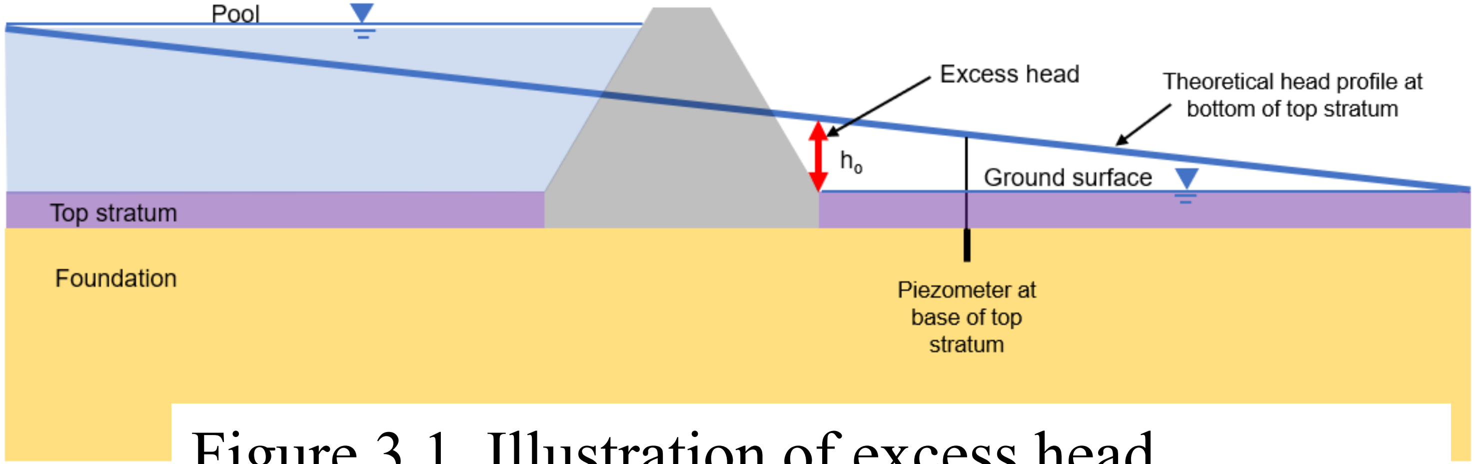


Figure 3.1. Illustration of excess head.

CHAPTER 4 - RISK CONSIDERATIONS

- Support Risk-Informed Design (RID)
- Evaluation of Existing Well Systems
- Long-Term O&M Considerations

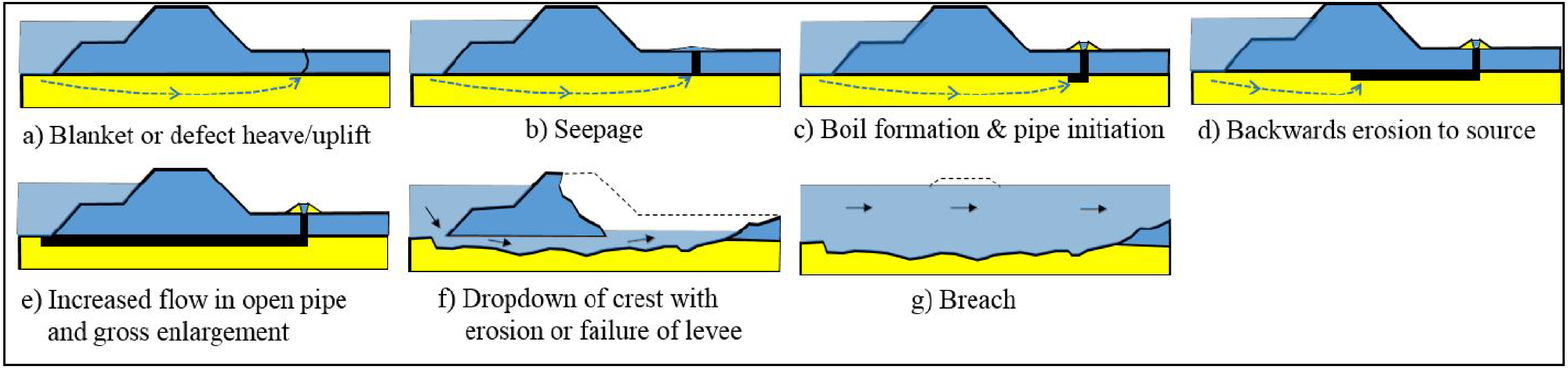


Figure 4.1. Internal erosion of the levee foundation materials due to underseepage (adapted from van Beek et al., 2010)

US Army Corps of Engineers

U.S. ARMY

CHAPTER 5 - ANALYSIS AND DESIGN OF AN INFINITE LINE OF WELLS

- Blanket Theory Approach
  - Retained from 1992 Version
  - Corrections and Updates
  - Simpler Design Charts
  - History in App H
- Extended to 2D FEM
  - Method in App G
- Examples in App I

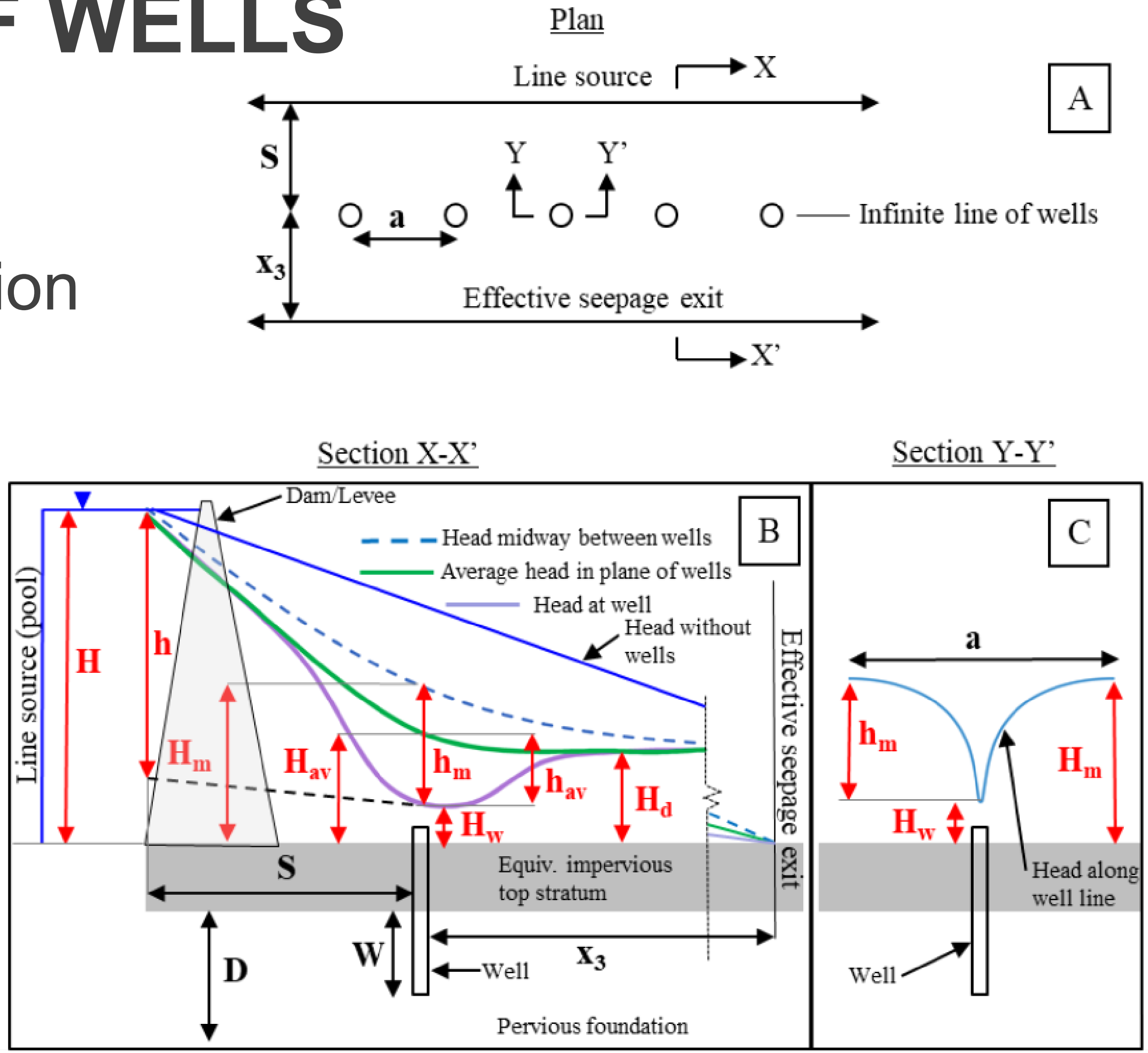


Figure 5.1. Infinite artesian relief well line

CHAPTER 6 - ANALYSIS AND DESIGN OF A FINITE LINE OF WELLS

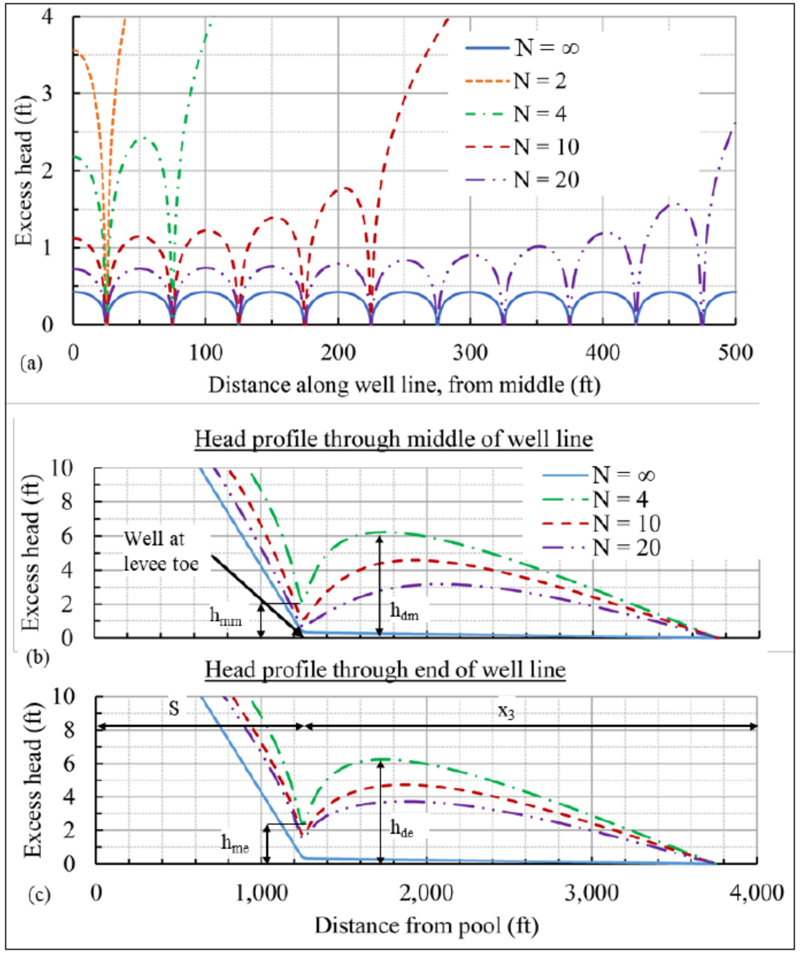


Figure 6.4. Profile of excess head along the well lines of various lengths

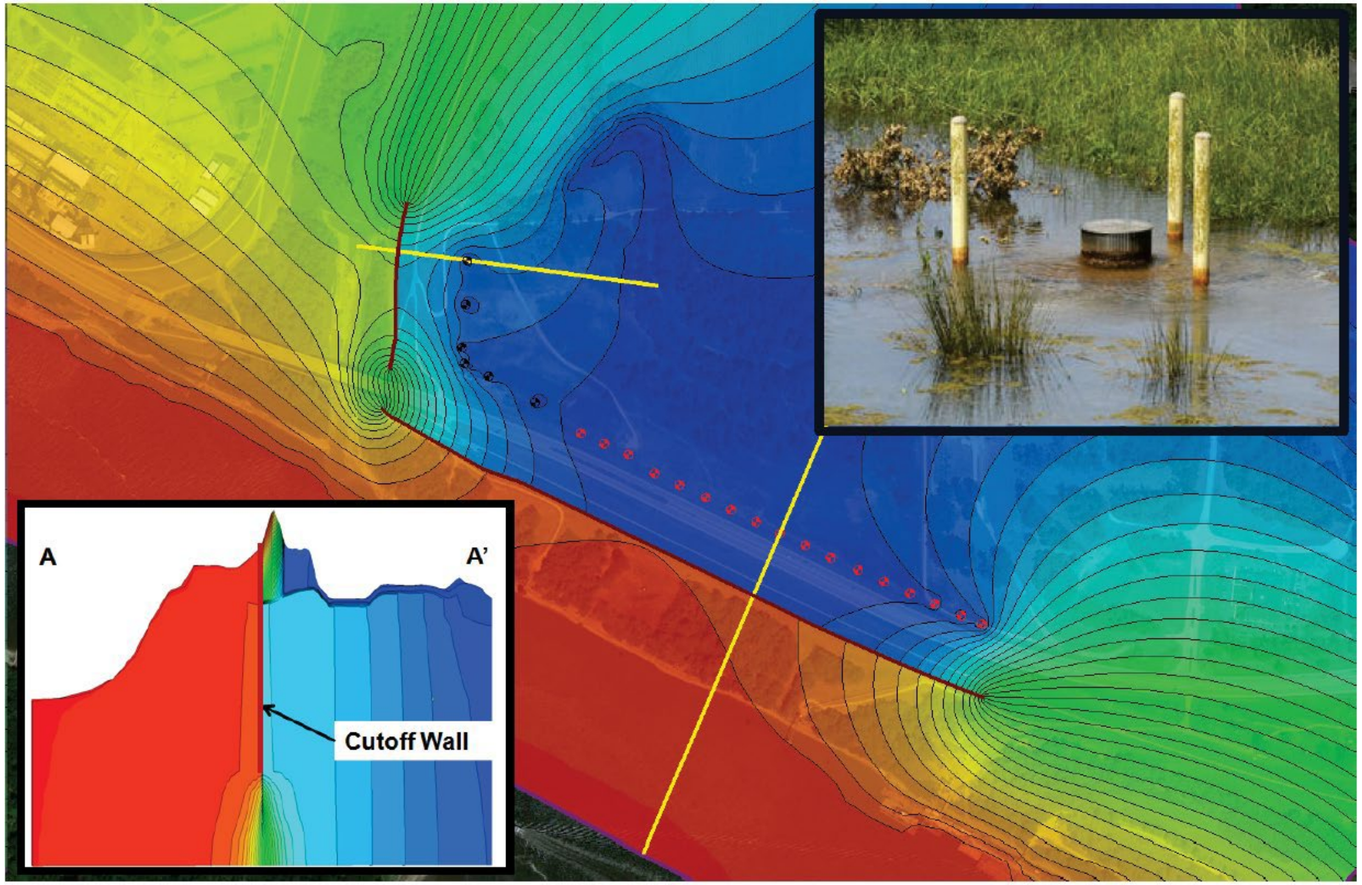


Figure 6.2. A WASH123D model including relief wells and cut-off

US Army Corps of Engineers

U.S.ARMY

CHAPTER 7 - DESIGN OF WELL AND SCREEN

All relief wells share the same basic elements:

- Drilled hole to facilitate the installation;
- Screen or slotted pipe section;
- Riser;
- Sump or bottom plate;
- Granular filter around screen;
- Check-valve to prevent backflooding;
- Backfill and seal above screened interval to prevent entry of surface water; and
- Protective cover to prevent vandalism and/or damage

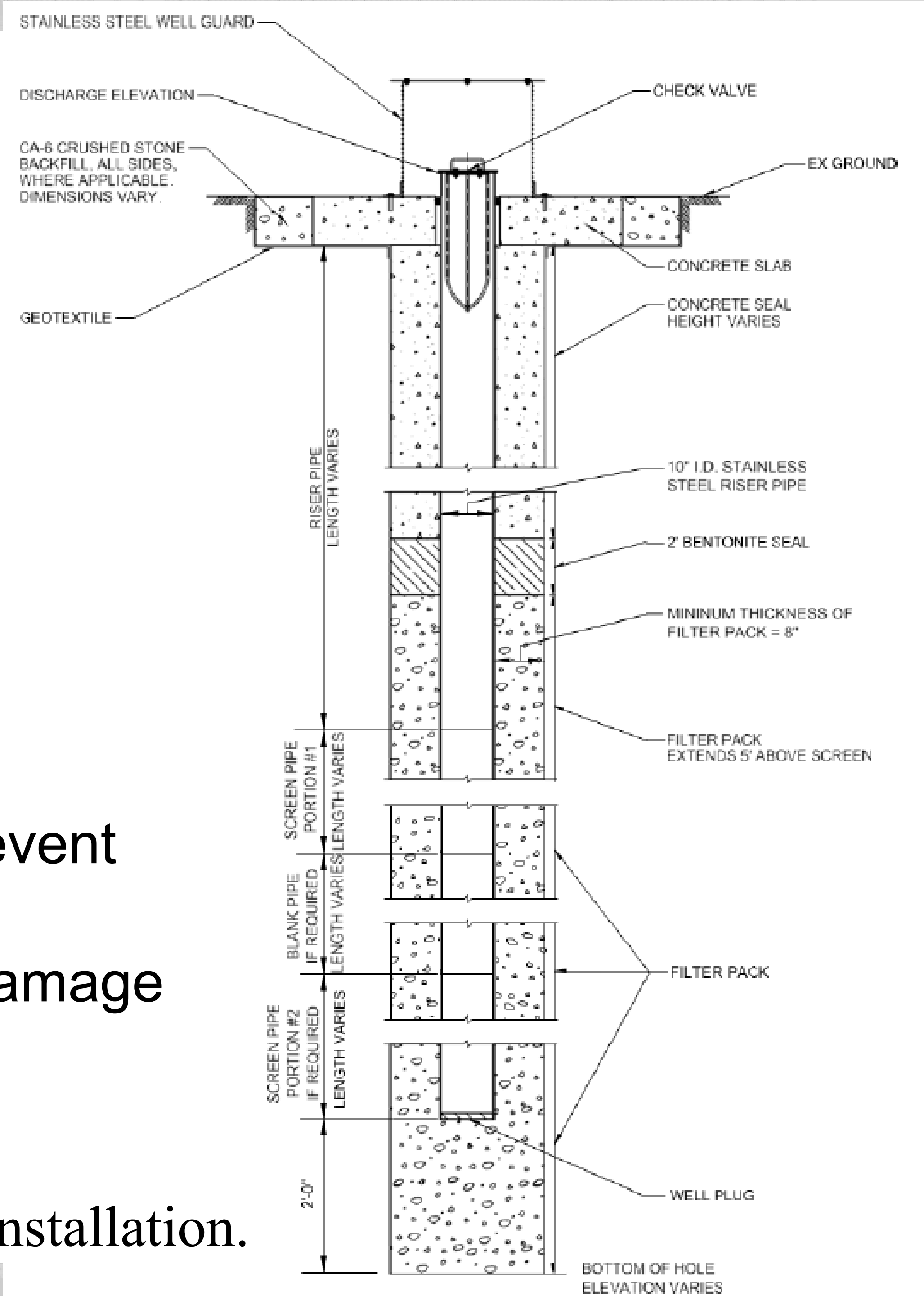


Figure 7.1. Typical relief well installation.

CHAPTER 8 - RELIEF WELL INSTALLATION

- Drilling and Borehole Requirements;
- Installation of Well Screen and Riser Pipe;
- Development;
- Sand Infiltration Testing;
- Initial Pumping Test;
- Backfilling;
- Disinfection;
- Video Inspection;
- Records; and
- Abandonment

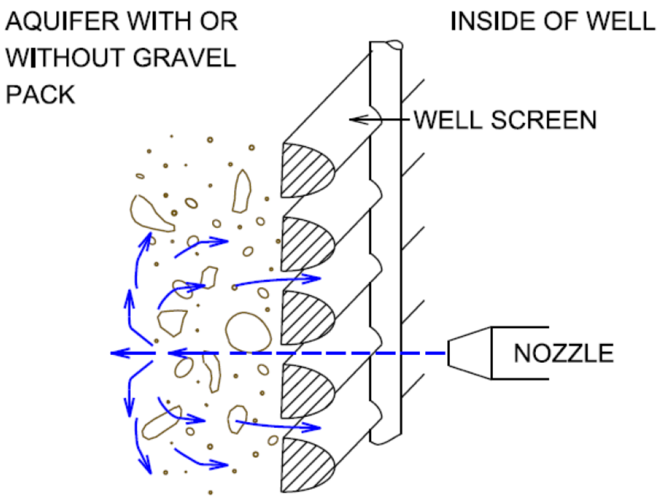


Figure 8.5. Well development by high-velocity jetting.

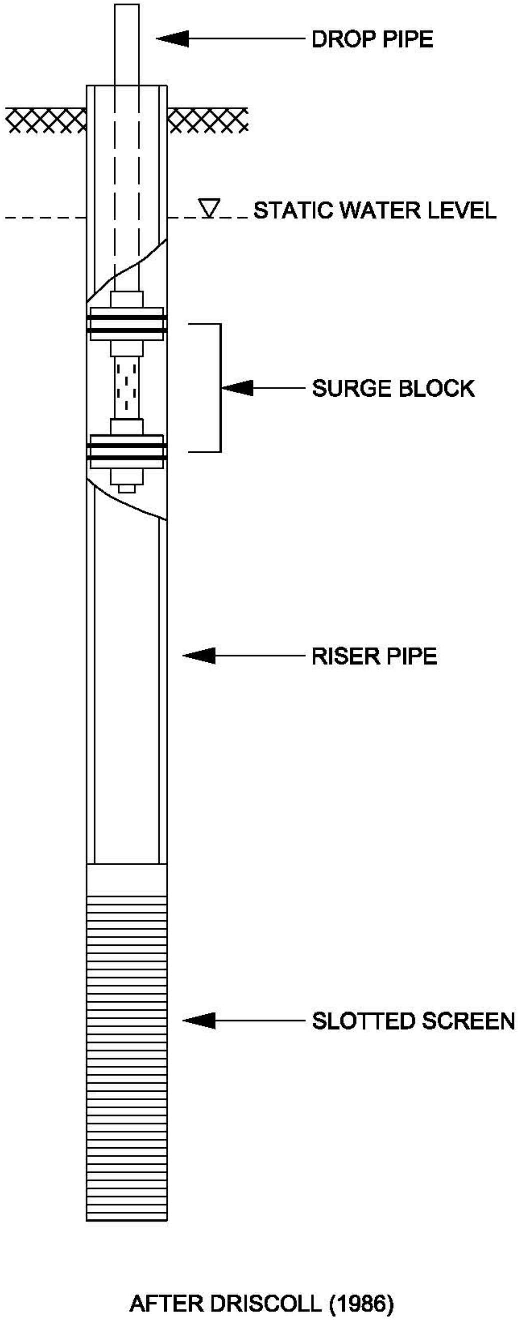


Figure 8.3. Surge block used to mechanically develop wells.

CHAPTER 9: RELIEF WELL PUMPING TEST, EFFICIENCY, AND WELL HEAD LOSS

- Pumping Test
- Specific Capacity (SCR)
  vs. Efficiency (E%)
- Efficiency Evaluation
- Well Head Loss Used in Design
  Well Loss Components

$$H_w = H_e + H_f + H_v$$

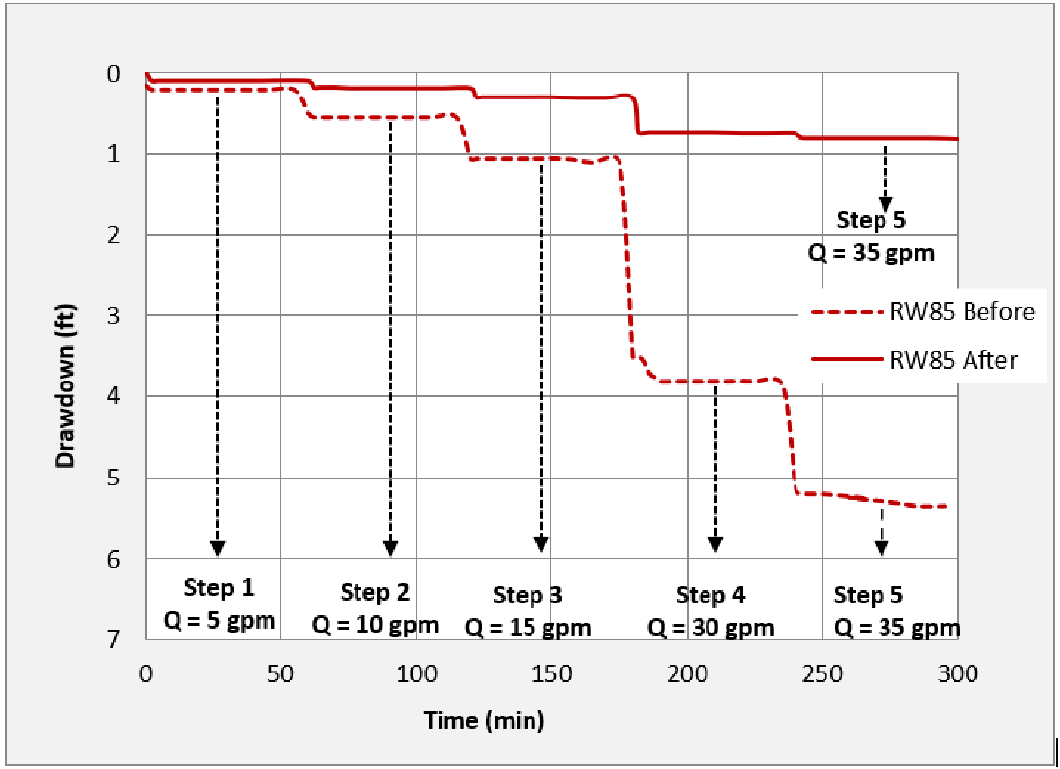


Figure 9.7. Step-drawdown test results: before and after rehabilitation

US Army Corps of Engineers
U.S. ARMY

CHAPTER 10 - RELIEF WELL COLLECTOR SYSTEMS

- Active vs. Passive Systems
- Below-grade Discharge
- Collector Ditches
- Components

Figure 10.4. Example of backup water in the housing (left) and full outlet pipe (right).

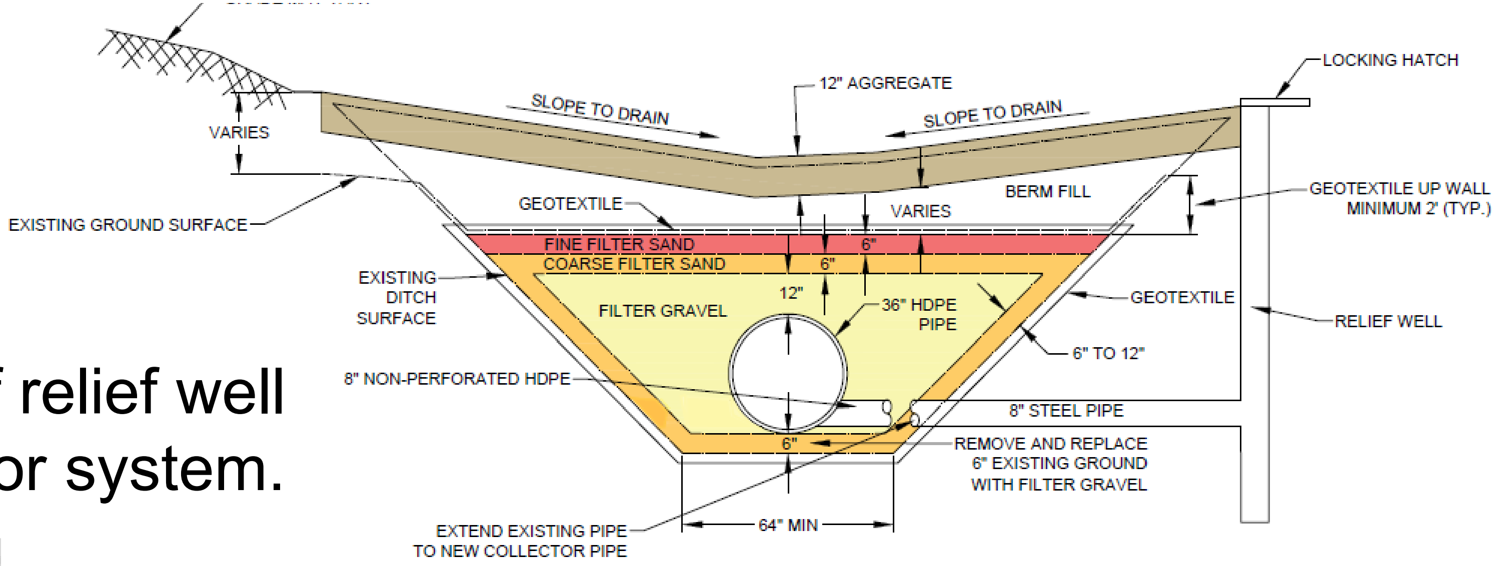


Figure 10.5. Example of relief well collector system.

CHAPTER 11 - OPERATION AND MAINTENANCE FOR WELL SYSTEMS

Best Practices

- Inspection
- Testing
- Evaluation
- Treatment

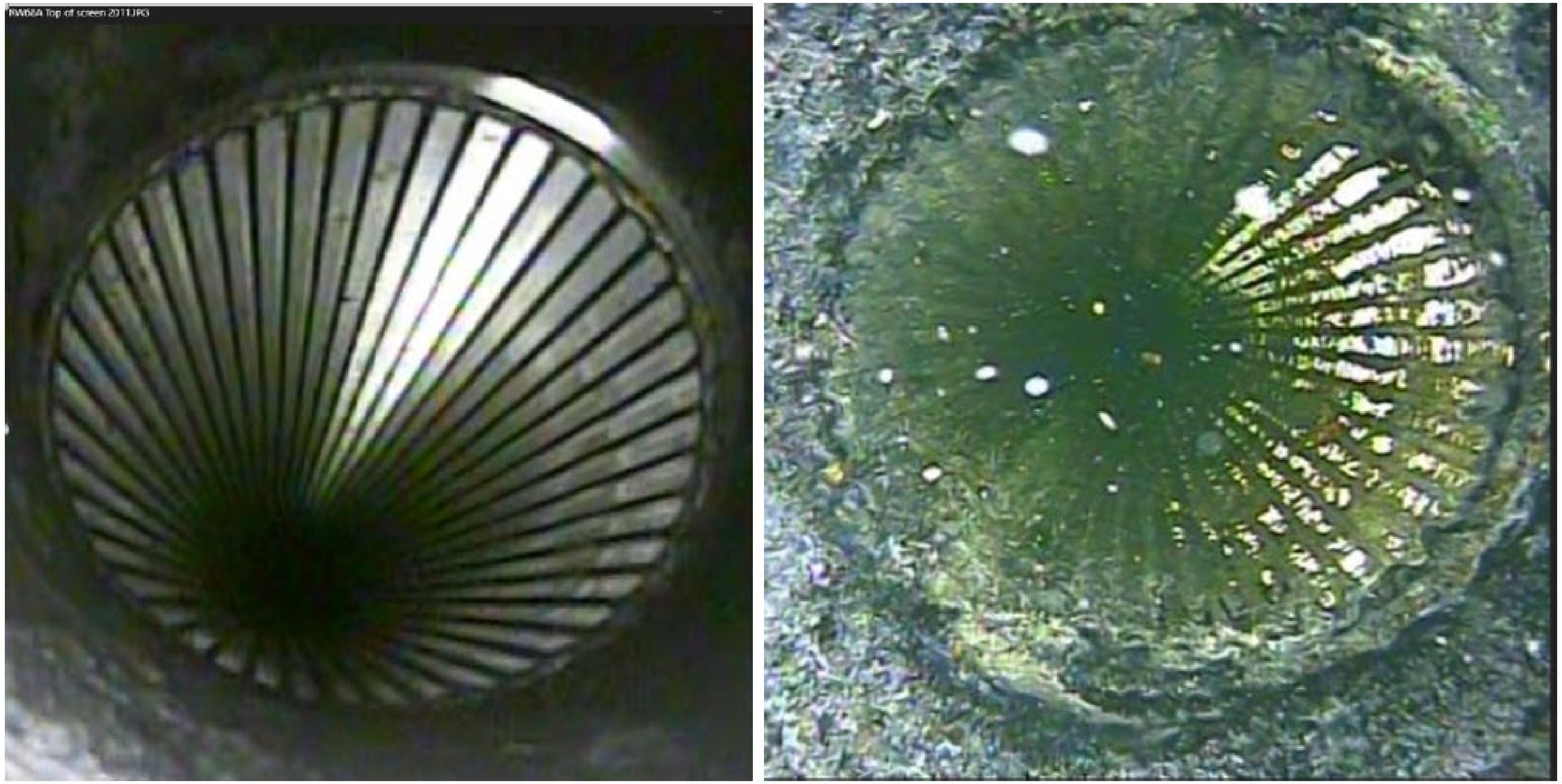


Figure 11.1. Example images from video inspections performed on RW 68A, Milford Dam, Junction City, KS. 2011 image (left) was obtained immediately after well rejuvenation. The 2020 image (right) was obtained prior to well rejuvenation.

APPENDICES

App A: References
App B: List of Symbols
App C: Mathematical Analysis of Underseepage and Substratum Pressure
App D: Image Well Theory and Other Analytical Well Solutions
App E: Partially Penetrating Wells and Stratified Aquifers
App F: 3D Finite Element Modeling of Relief Wells in a Transformed Aquifer
App G: Seepage Analysis Using the Finite Element Method for Relief Wells
App H: History of Well Factors for an Infinite Line of Partially Penetrating Relief Wells
App I: Example Relief Well Calculations
App J: Application of Pumping Test Data in the Evaluation of Relief Wells
App K: Numeric Analyses of Physical Tank Tests

APP C: INTRO TO BLANKET THEORY (BT)

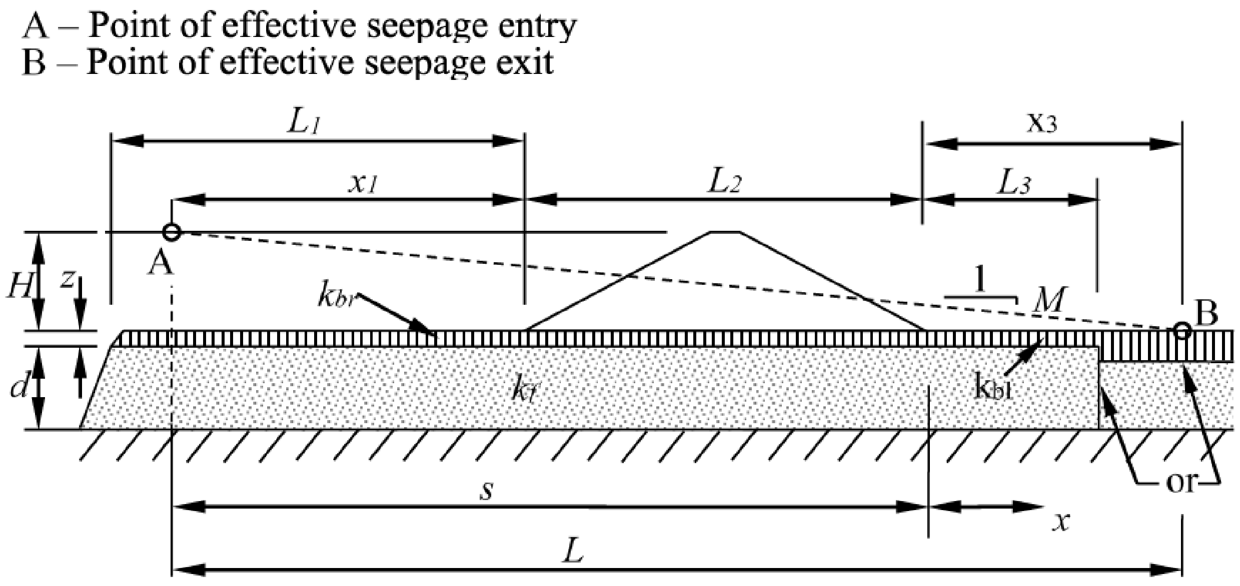
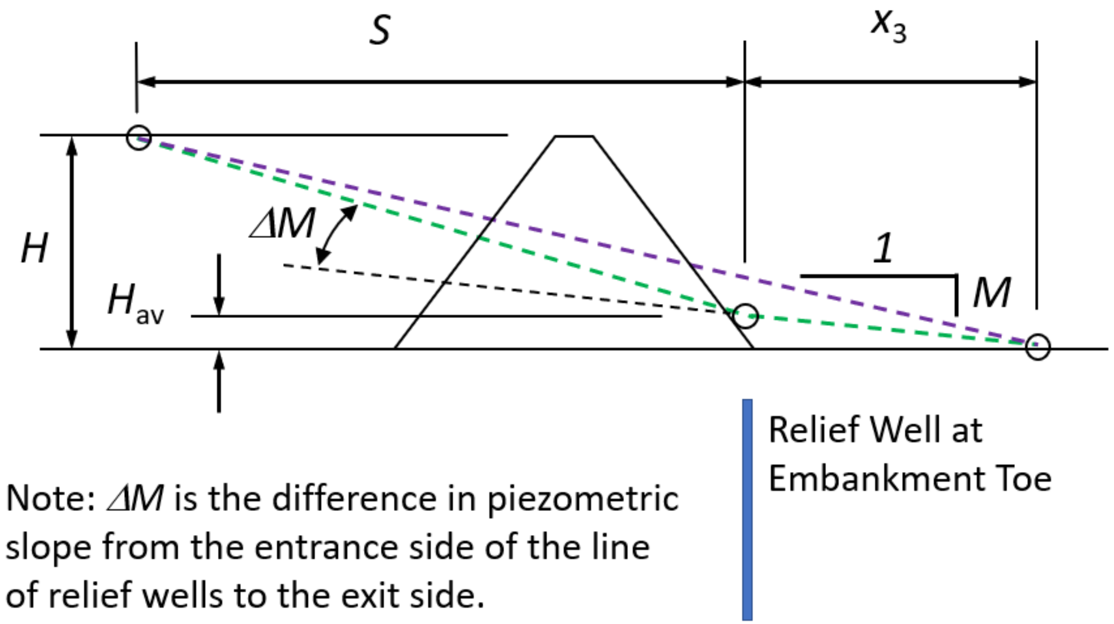


Figure C.1. Illustration of symbols used in Appendix C.

Figure C.3. Illustration of Change in Pressure due to Line of Relief Wells.



APP D: IMAGE WELL THEORY

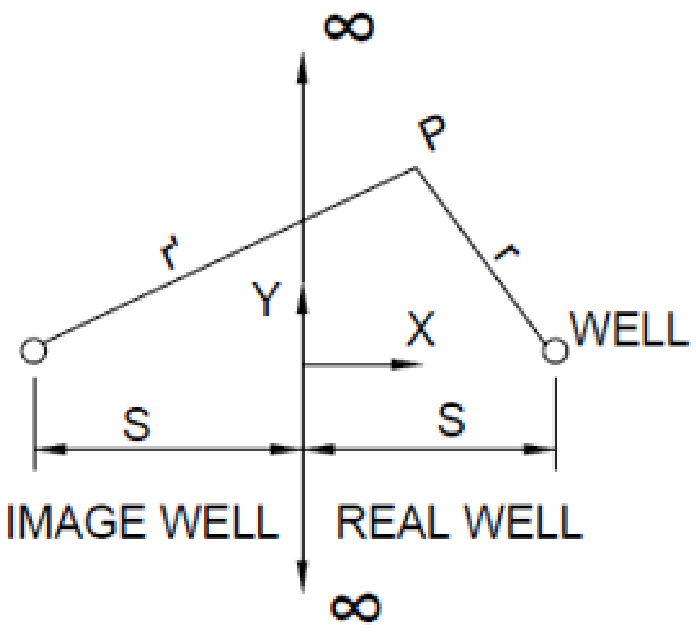


Figure D.4. Artesian flow to a single well with an infinite line source.

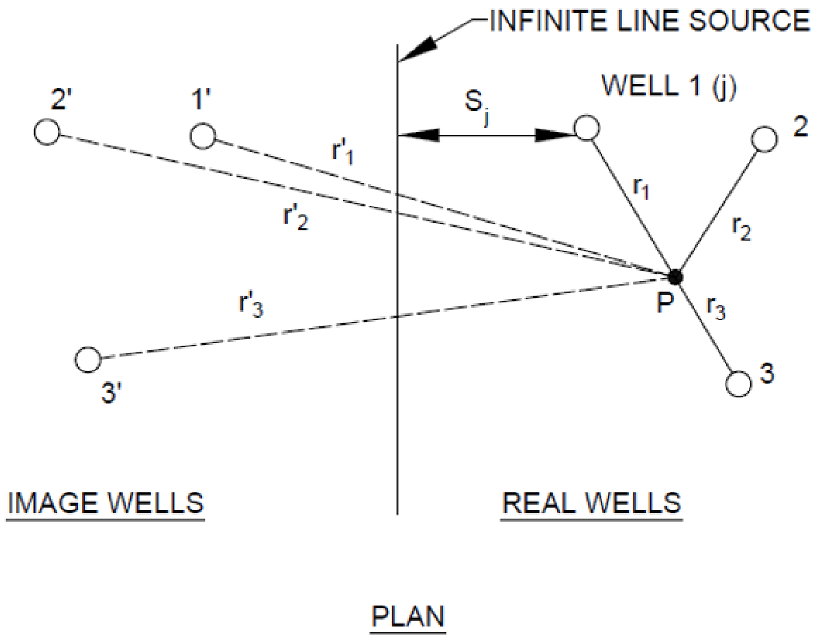


Figure D.5. Artesian flow to multiple wells with an infinite line source.

US Army Corps of Engineers

U.S. ARMY

APP E: PARTIALLY PENETRATING WELLS AND STRATIFIED AQUIFERS

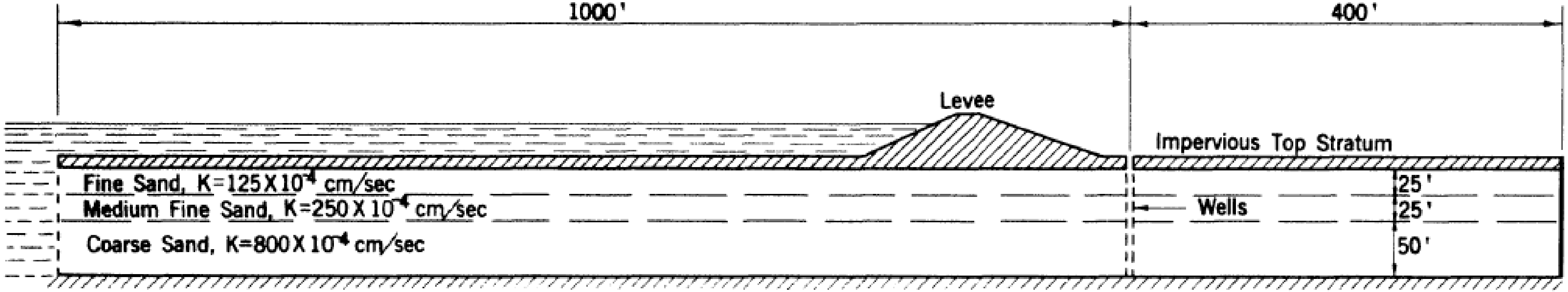


Figure E.4. Schematic of physical model test with a stratified sand aquifer.

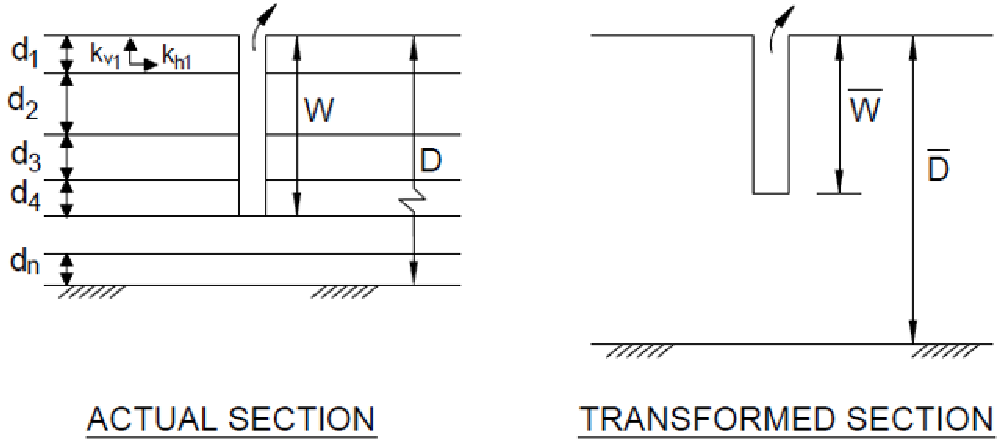


Figure E.2. Comparison of actual and effective well penetration.

US Army Corps of Engineers

U.S.ARMY

APP F: 3D MODEL OF TM 3-304

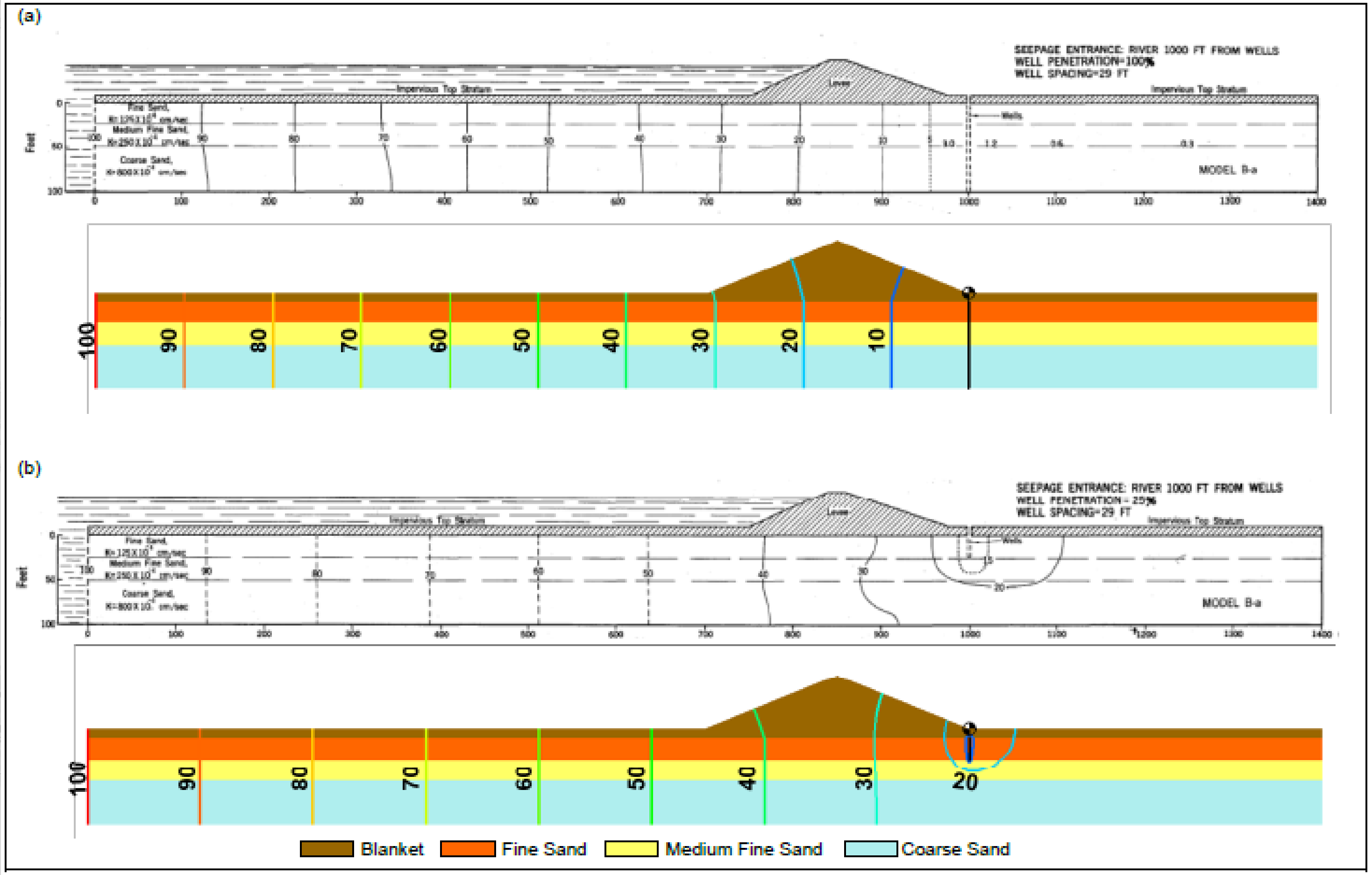


Figure F.9. Comparison of equipotential lines in percent of net head from Physical Model B-a (WES, 1949, Figure 30) and Numerical Model #1 for 29 ft well spacing and (a) 100% well penetration or (b) 25% penetration.

Table F.12
Mid-well head summary. 80% vs. 100% Efficiency.

Well Penetration (Effective)	Mid-Well Head (ft)			Mid-Well Head (%H)		
	80% Efficient Calc. Estimate*	3-D Model Results		80% Efficient Calc. Estimate*	3-D Model Results	
		80% Efficient	100% Efficient		80% Efficient	100% Efficient
100% (100%)	421.69	422.27	413.09	23.37	24.55	6.17
50% (19%)	426.55	426.29	419.16	33.10	32.57	18.33
25% (6.3%)	435.13	435.17	429.89	50.27	50.34	39.79
10% (2.5%)	442.67	442.62	439.32	65.35	65.25	58.64
No Wells	456.09	456.09	456.09	92.18	92.18	92.18

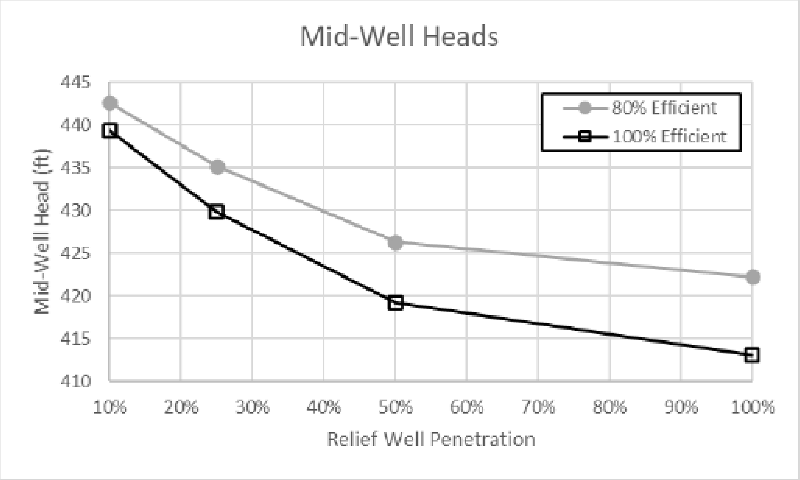


Figure F.14. Heads computed mid-way between relief wells for 80% and 100% efficiency.

US Army Corps of Engineers.

U.S. ARMY

APP F: 3D MODEL OF TM 3-304

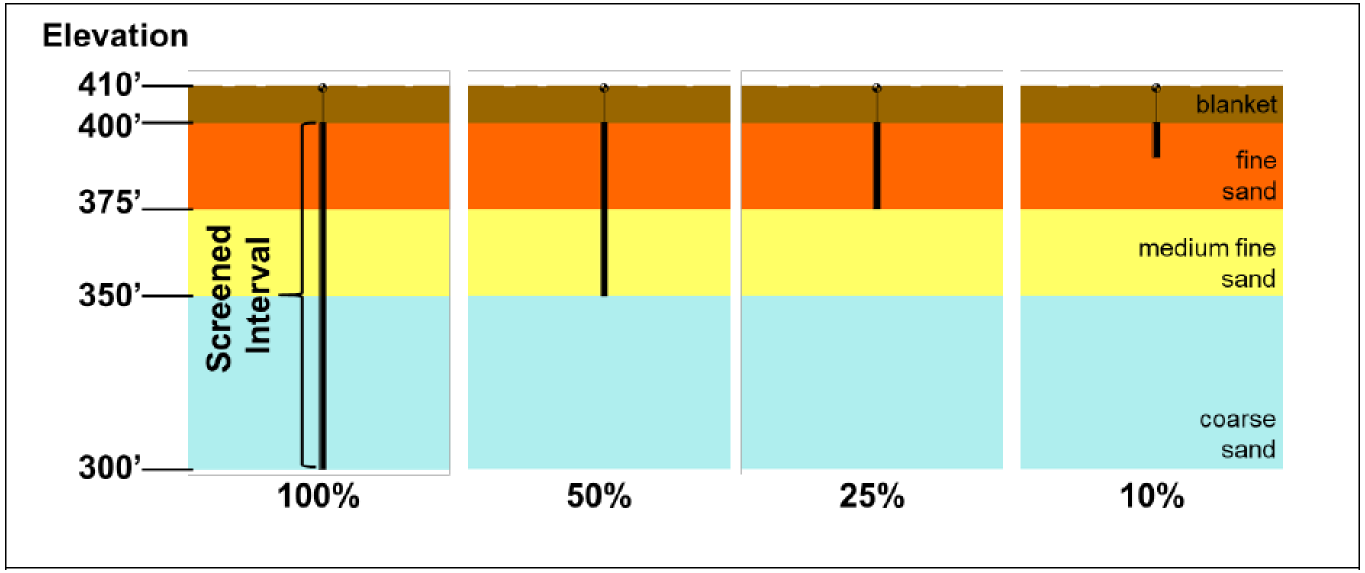


Figure F.3. Modeled relief well penetration.

Sensitivity studies
- 80% SCR
- Transformed aquifer
- Blank top 20' of well
  - 10' blanket
  - + 10' fine sand
- Blanket defect

1.5' diameter sand-filled hole

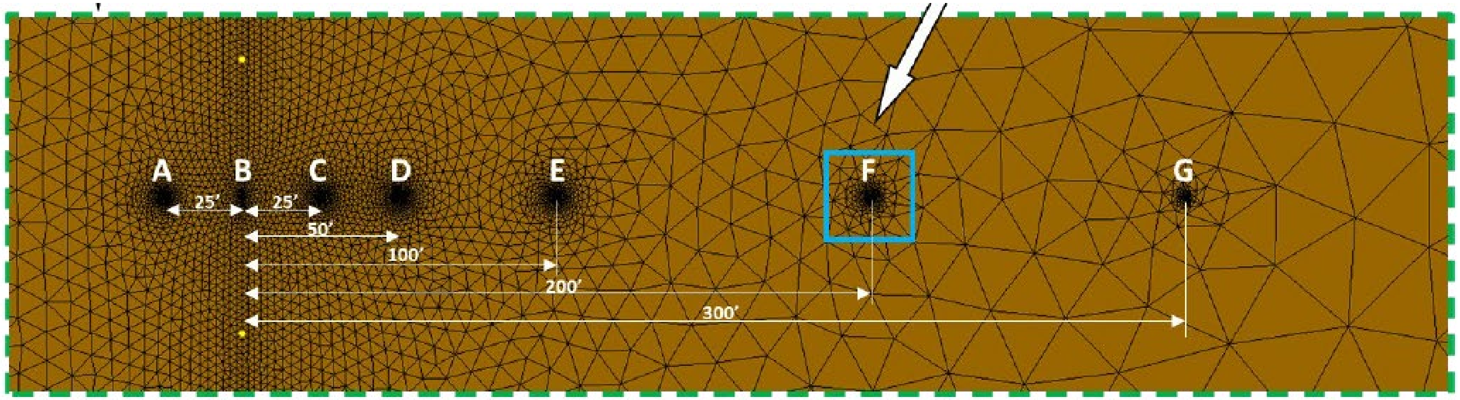


Figure F.18. Blanket defect model setup. (Full model domain not pictured.)

US Army Corps of Engineers

U.S. ARMY

App G: 2D FEM (Modeling wells in SeepW)

Partial penetrating wells are complex, but that complexity is resolved by the well factors, θ_{av} and θ_m

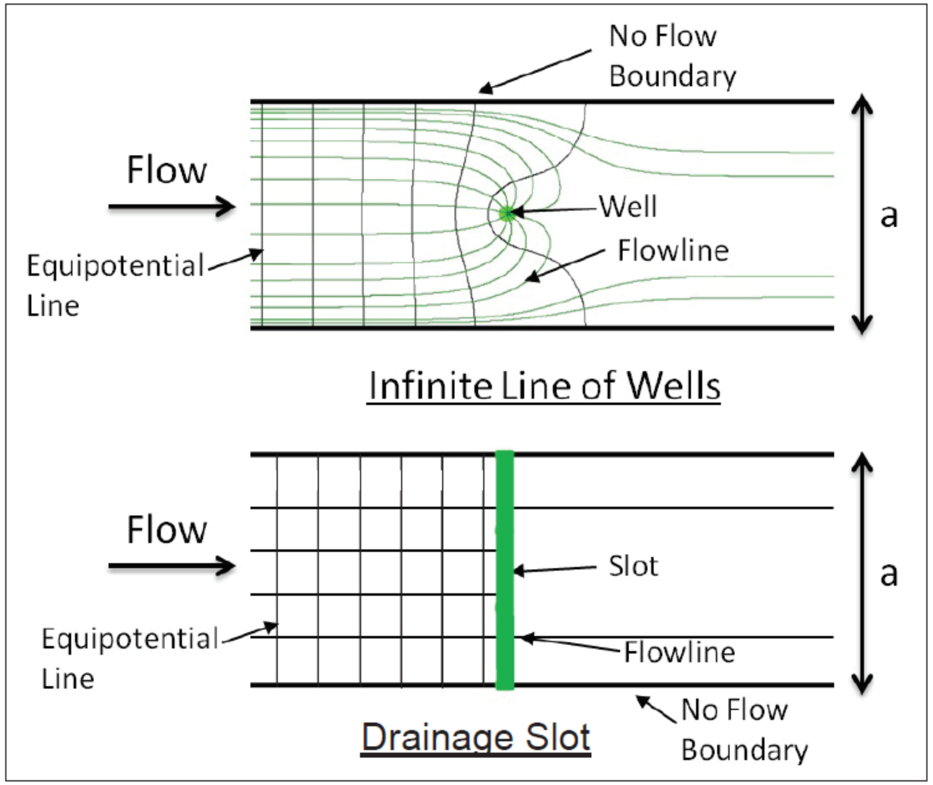


Figure G.1. General plan view flow net of a fully penetrating infinite well line and a fully penetrating drainage slot.

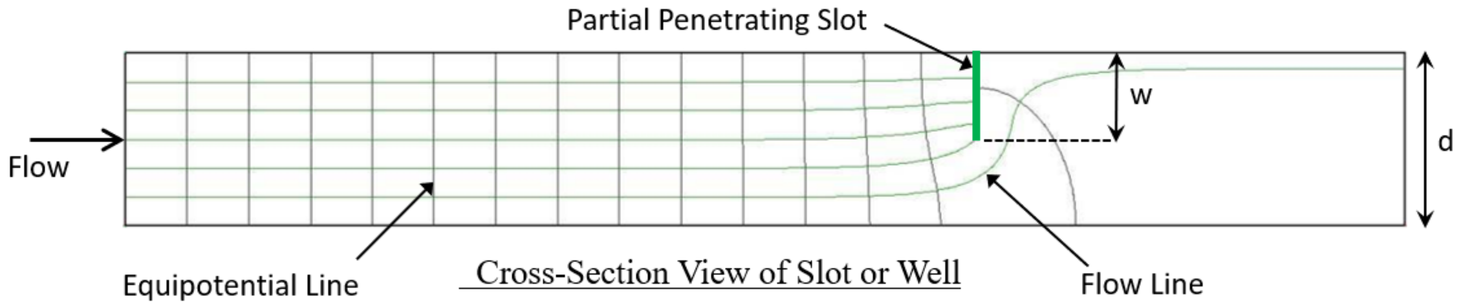


Figure 5.3. Cross-section view of a flow net to a partially penetrating drainage slot.

App H: History of well factors, θ_{av} and θ_m

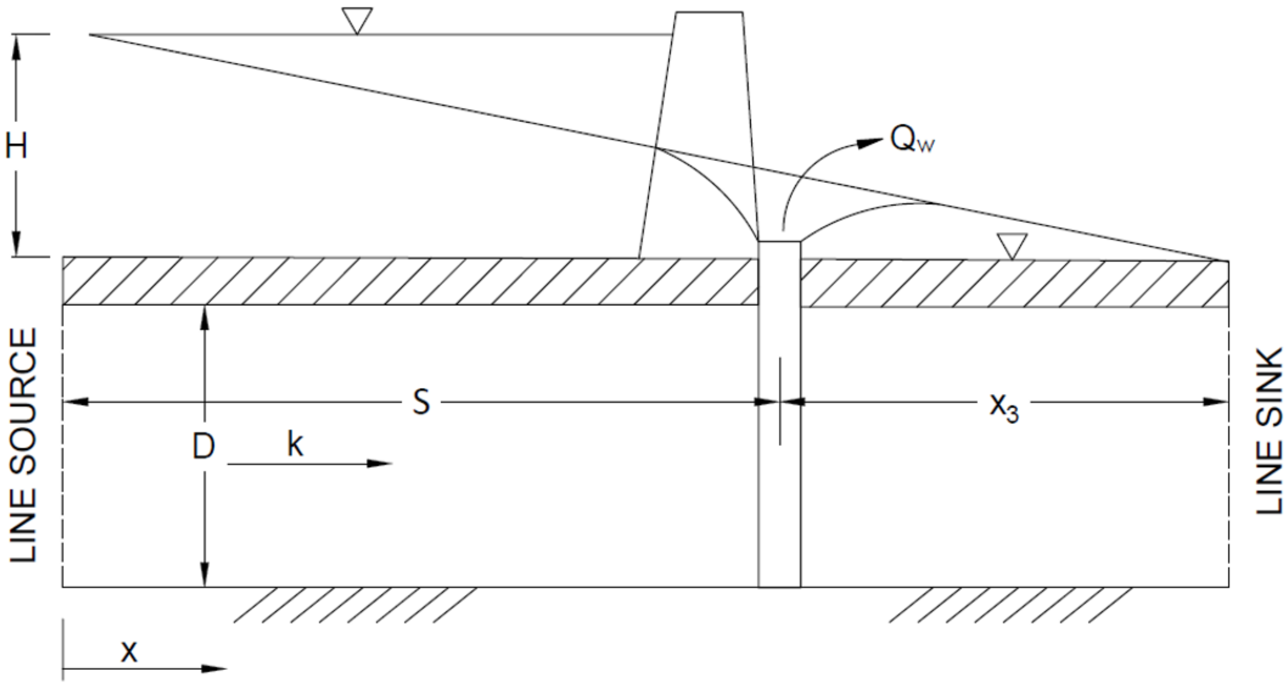


Figure H.2. Drawdown for well between infinite line source and downstream sink (after Barron, 1948).

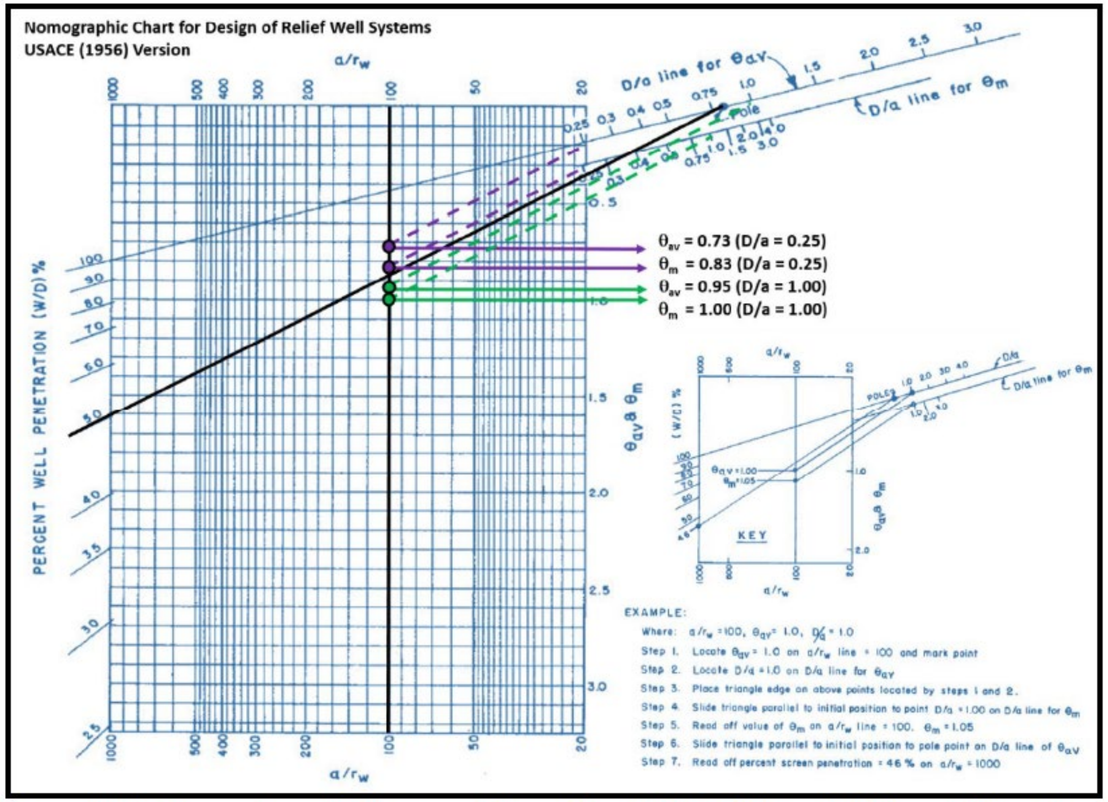


Figure H.8. Example uplift factor solutions (for W/D = 50% and different D/a values) using the USACE design nomogram.

Provide simpler tables for practitioners, Sharma's approach

App I: Examples; BT & Image Wells (left), FEM (right), Plan view (bottom)

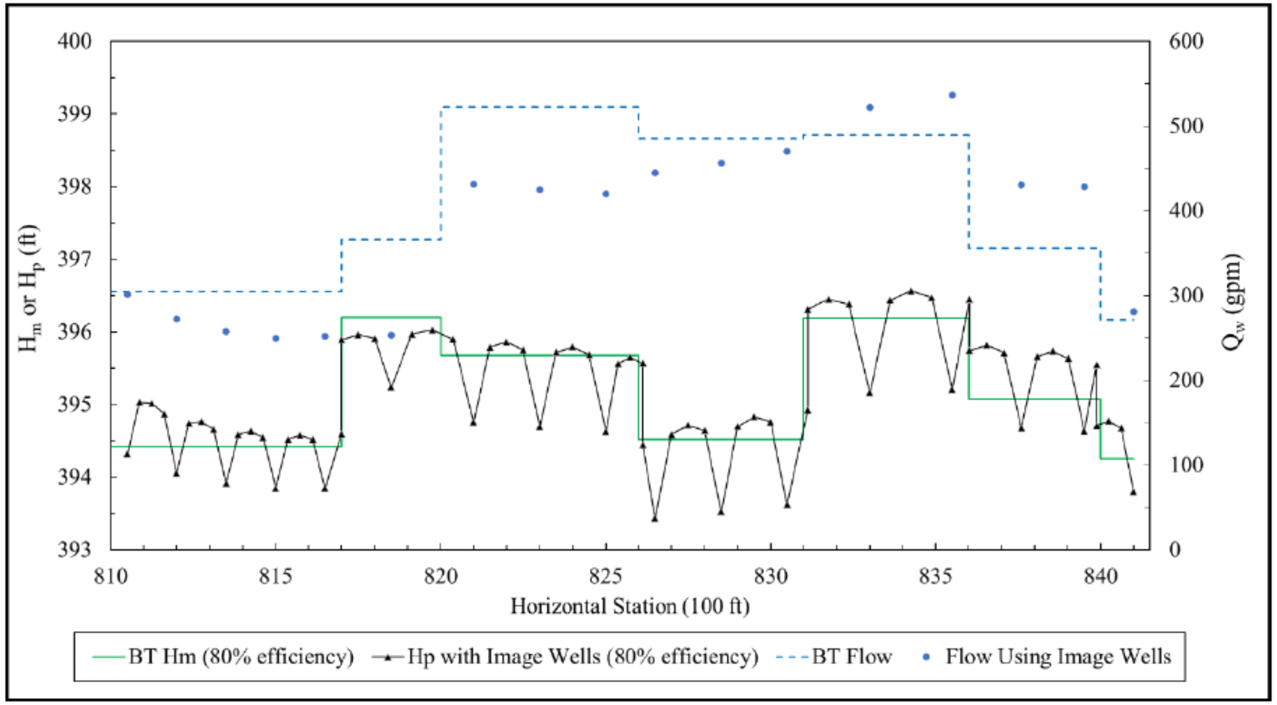


Figure I.5. Example of Image Well Method compared with Infinite Well Approach (Chapter 5).

Table I.4
Iterative relief well head loss calculations for well spacing of 170 foot

TH_{well} (ft)	q_{slot} (gpm/ft)	Q_w (gpm)	H_w (ft)	H_m ($h_{\Delta M}$) (ft)	H_{av} ($h_{\Delta L}$) (ft)	$TH_{well\text{-}m}$ (ft)	$TH_{well\text{-}av}$ (ft)
410	3.49	593	1.17	5.27	4.75	416.44	415.92
412.96	2.61	444	0.85	3.95	3.56	414.79	414.40
413.68	2.40	407	0.78	3.62	3.26	414.40	414.04
413.86	2.34	398	0.76	3.54	3.19	414.30	413.95
413.91	2.33	396	0.76	3.52	3.17	414.28	413.93
413.92	2.33	395	0.76	3.52	3.17	414.27	413.92

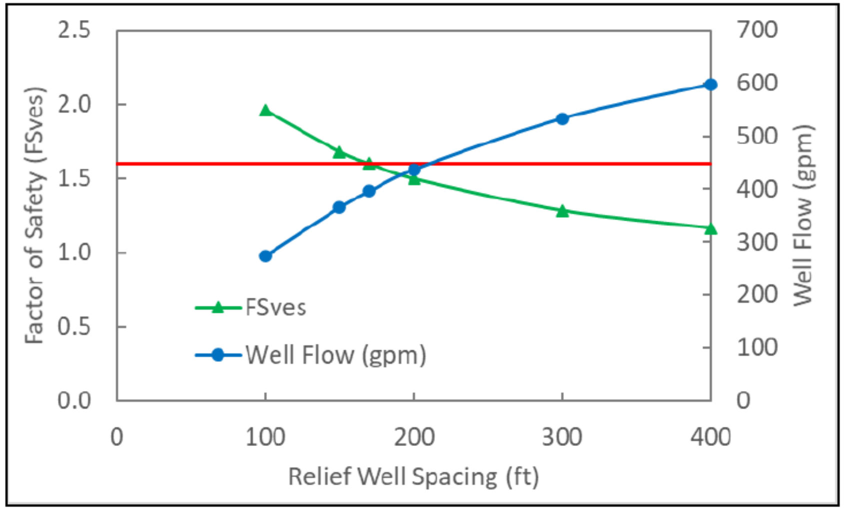


Figure I.12. FS_{ves} versus relief well spacing to achieve target value of FS_{ves}=1.6.

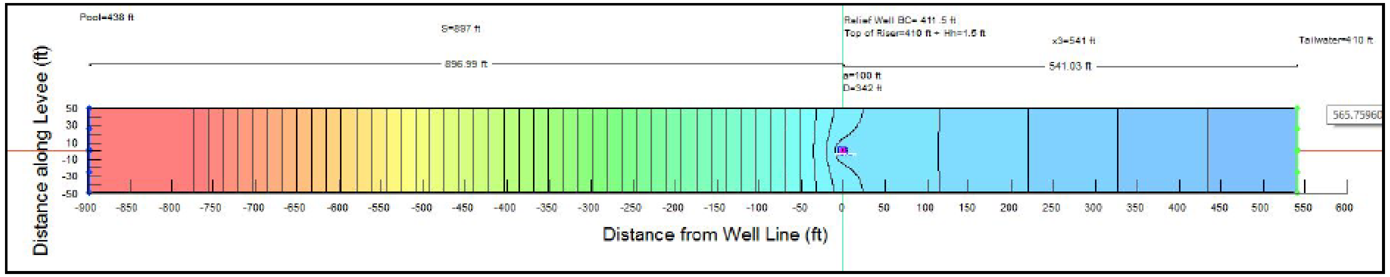


Figure I.14. Total head contours in a plan view model of the generalized levee cross section.

App J: Evaluation of Pumping Tests

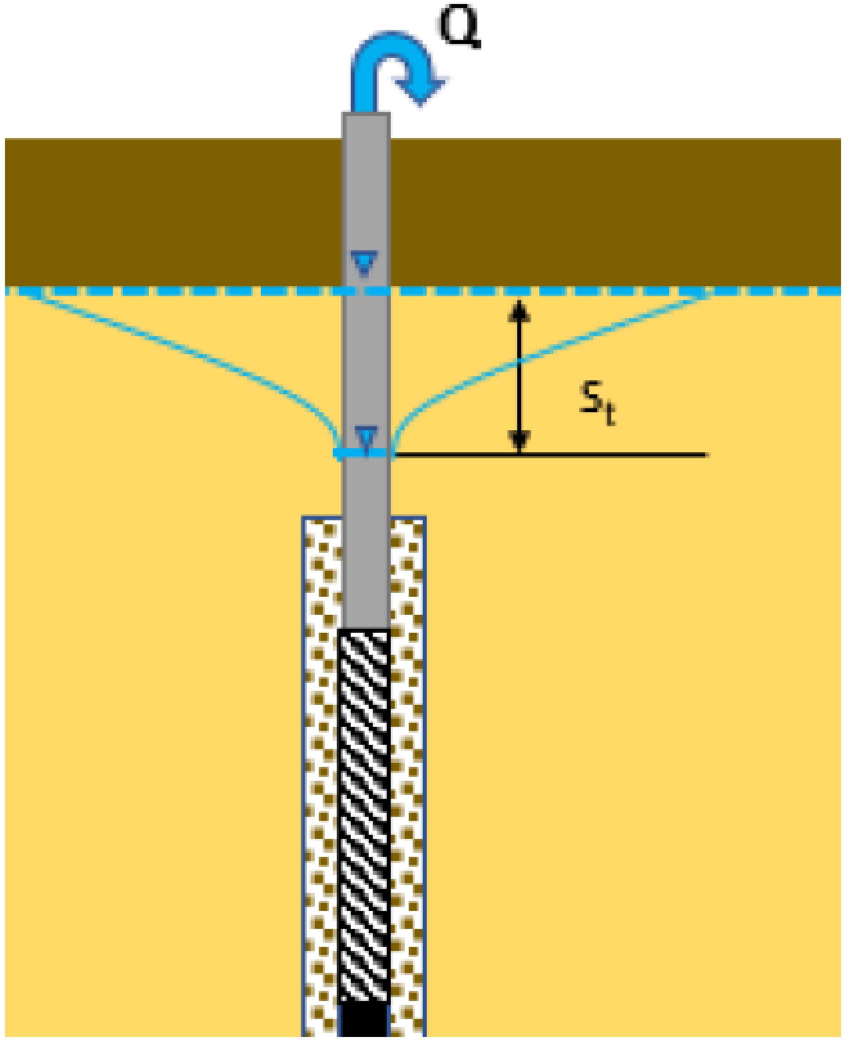


Figure J.1. Illustration of specific capacity variables.

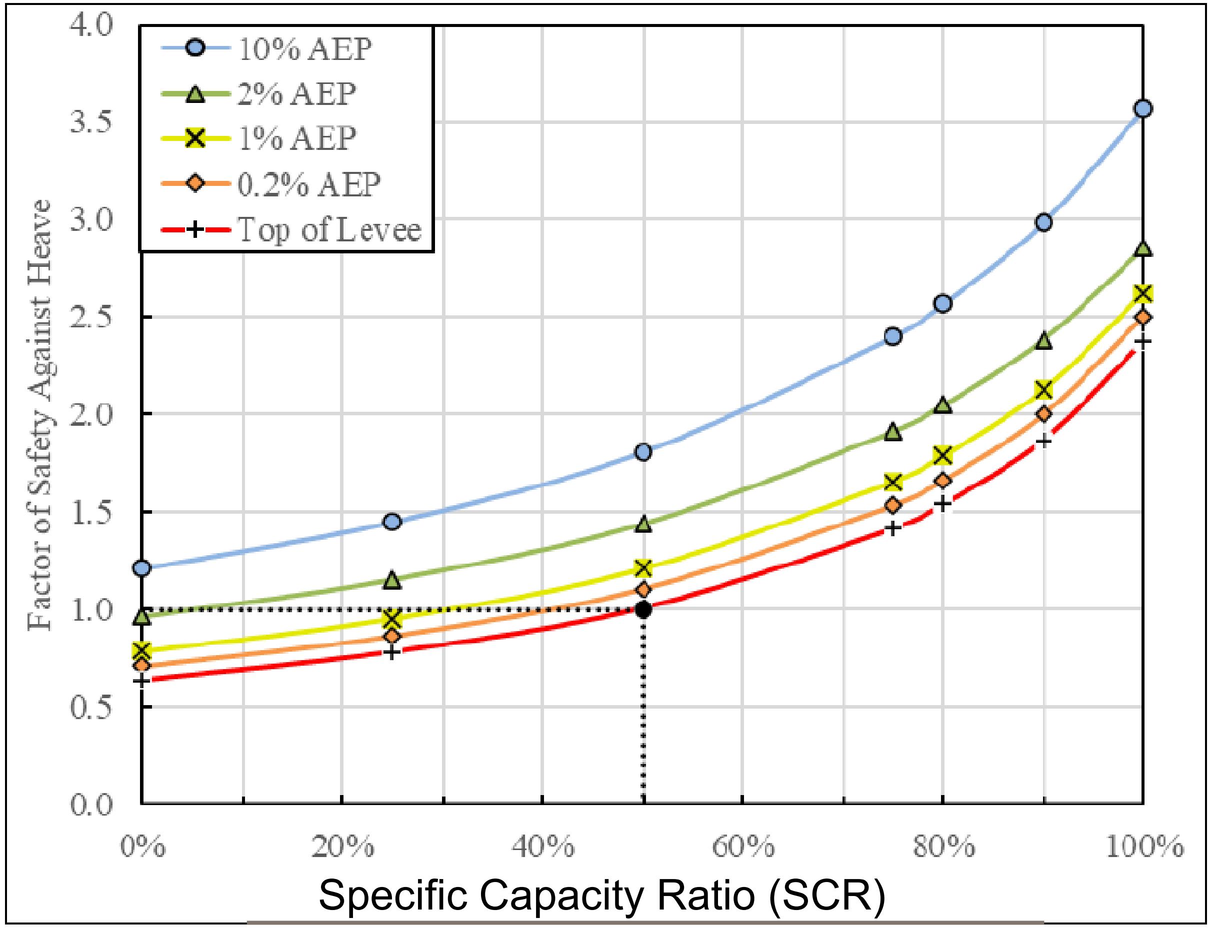


Figure J.11. Factor of safety (heave) vs. well efficiency (Example 5).

App K: Plan view and Axisymmetric FEM of tank tests

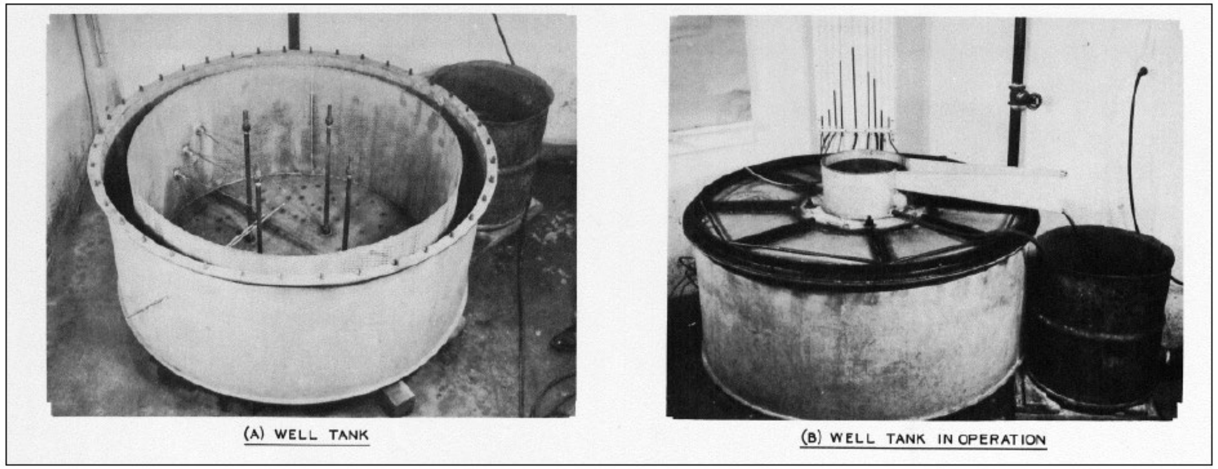


Figure K.1. Tank used for relief well tests (TM 3-341, 1952).

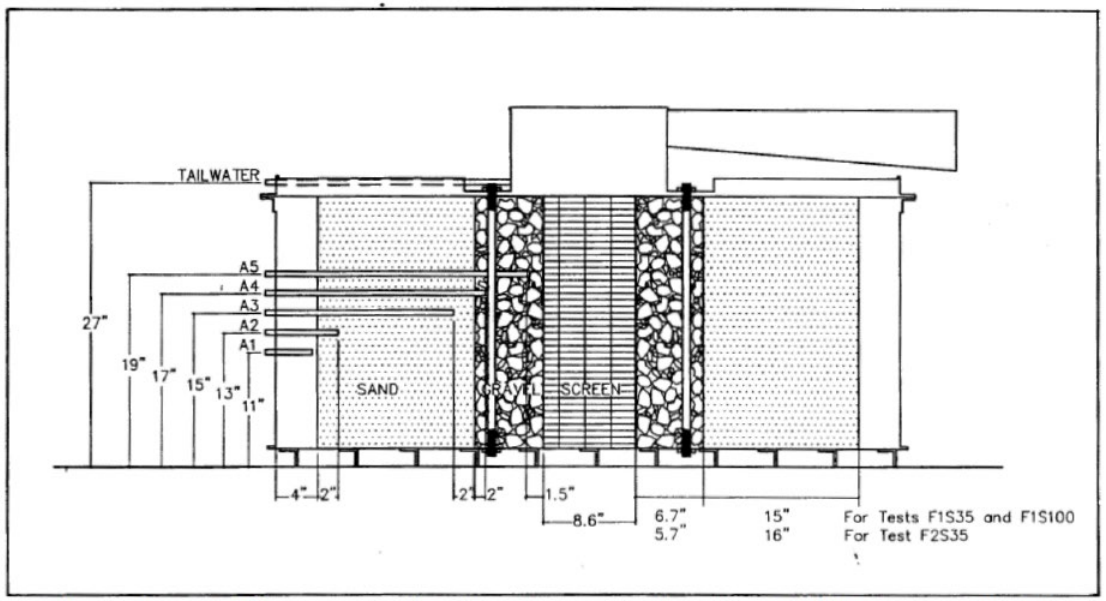


Figure K.4. Testing apparatus showing piezometer elevations (Hadj-Hamou et al. 1988).

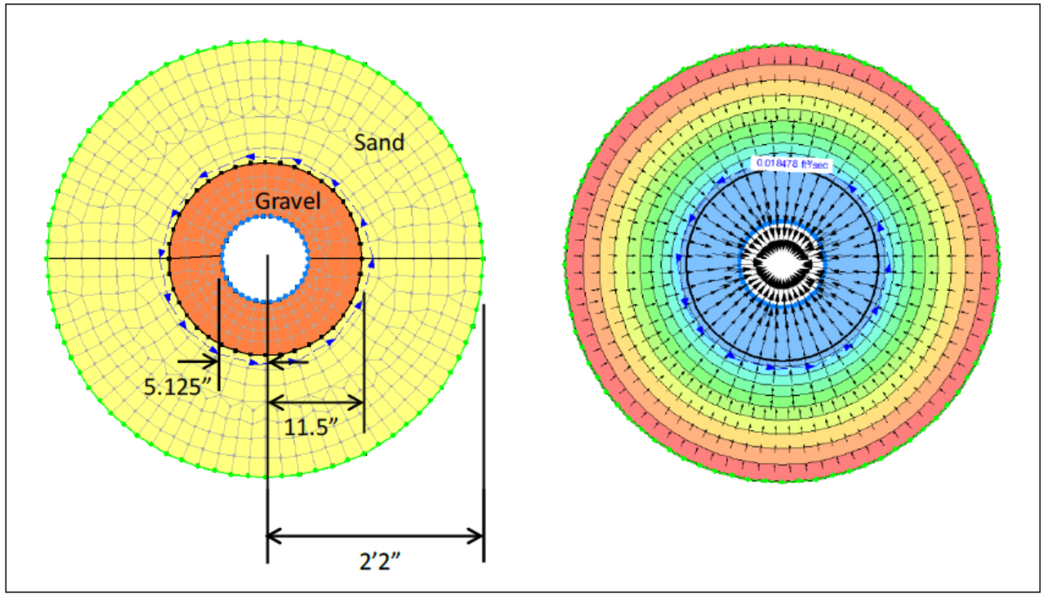


Figure K.9. Input and output of simple plan view model of Mitronovas (1968) Test 1.

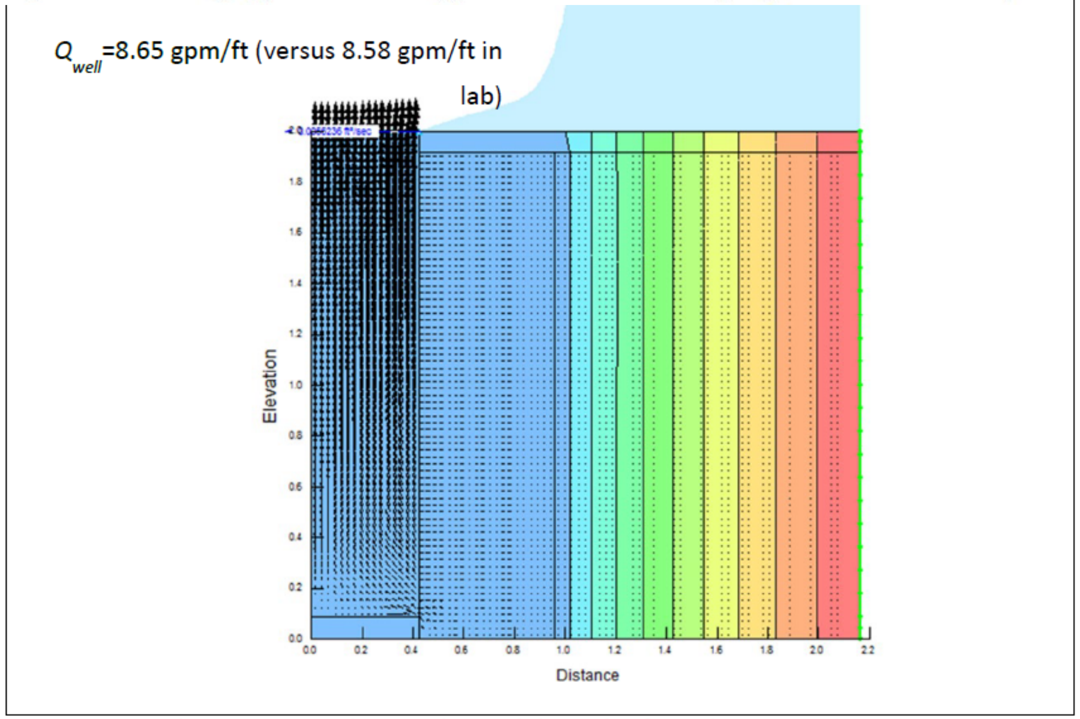


Figure K.8. Axisymetric model results for Mitronovas (1968).

WHAT YOU SHOULD KNOW

Where to get it:

Levee Safety Program Website

What to do with it:

1. Review and provide feedback by **January 31**
2. Share with partners and encourage feedback

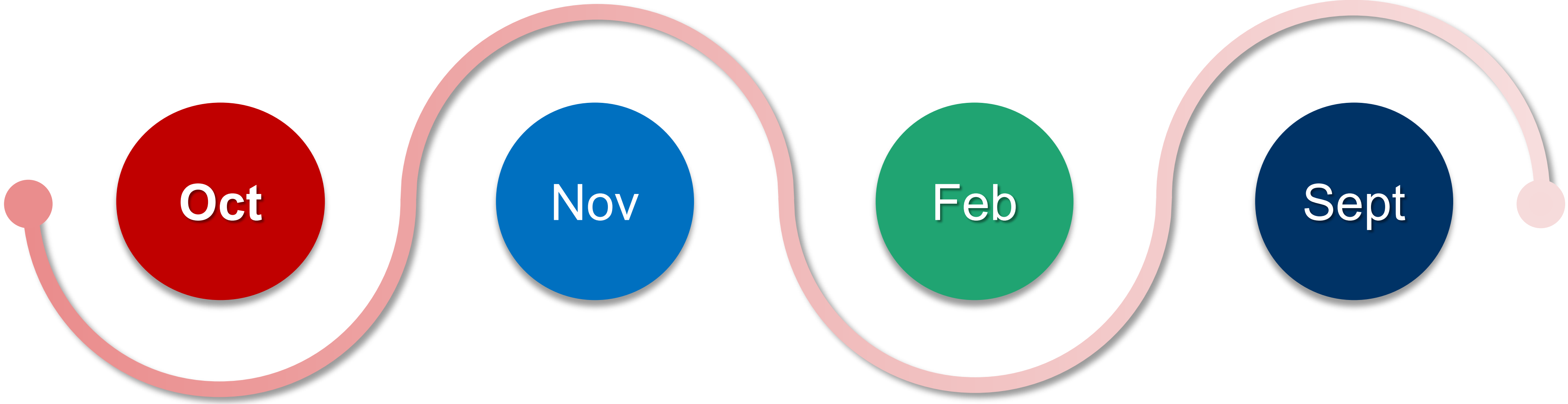
How to learn more:

INTERNAL	EXTERNAL
Informational Webinar September 27	Informational Webinar October 25

US Army Corps of Engineers

U.S. ARMY

OVERALL SCHEDULE WITH 120-DAY REVIEW



USACE review

USACE will have 30 days to review EM 1110-2-1914 before it is shared externally

Open review

Partners will have 90 days to review EM 1110-2-1914

Comment review

USACE will review comments and update EM 1110-2-1914

Guidance final

USACE will publish EM 1110-2-1914 by the end of fiscal year 2023

USACE and External Comments Due – Jan 31

WHO SHOULD REVIEW

1. Dam and Levee Safety Staff
2. Geotechnical Professionals (Engineers & Geologists)
3. Operations & Maintenance Staff
4. Emergency Management

US Army Corps of Engineers

U.S. ARMY

HOW TO PROVIDE COMMENTS

Submit All comments/questions via email:

EM1914@usace.army.mil

US Army Corps of Engineers

U.S. ARMY

QUESTIONS?

Primary Authors:
Mike Navin (LSC),
Glen Bellew (NWD), Chapter 3 (Design Considerations), Image Well Theory
Thom Davidson (RMC), Chapter 4 (Risk and Reliability)
Erich Guy (LRH), Andrew Keffer (LRH), Chapters 5, 6 (Infinite and Finite Well Lines)
Lizzy Chang (LRH), Chapter 7 (Well Design)
Bill Niemann (LRH), Chapters 8 and 11 (Installation, O&M)
Kenneth Darko-Kagya (SWG), Chapter 9 (Pumping Tests)
Tricia North (NAP), Appendix F (WASH123D Model)
Stefan Flynn (MVR), Appendix J (Evaluation of Pumping Tests)

EM1914@usace.army.mil