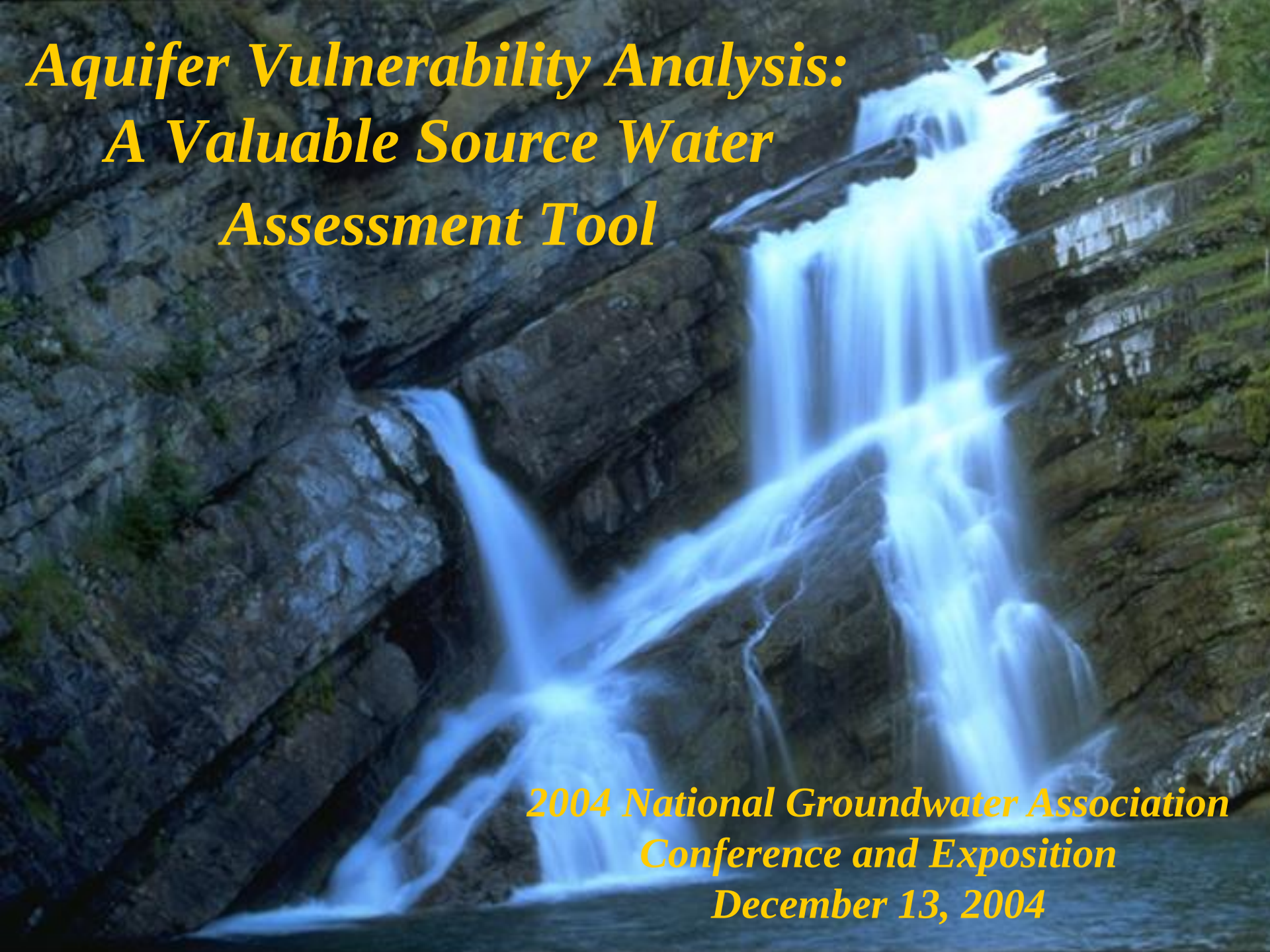
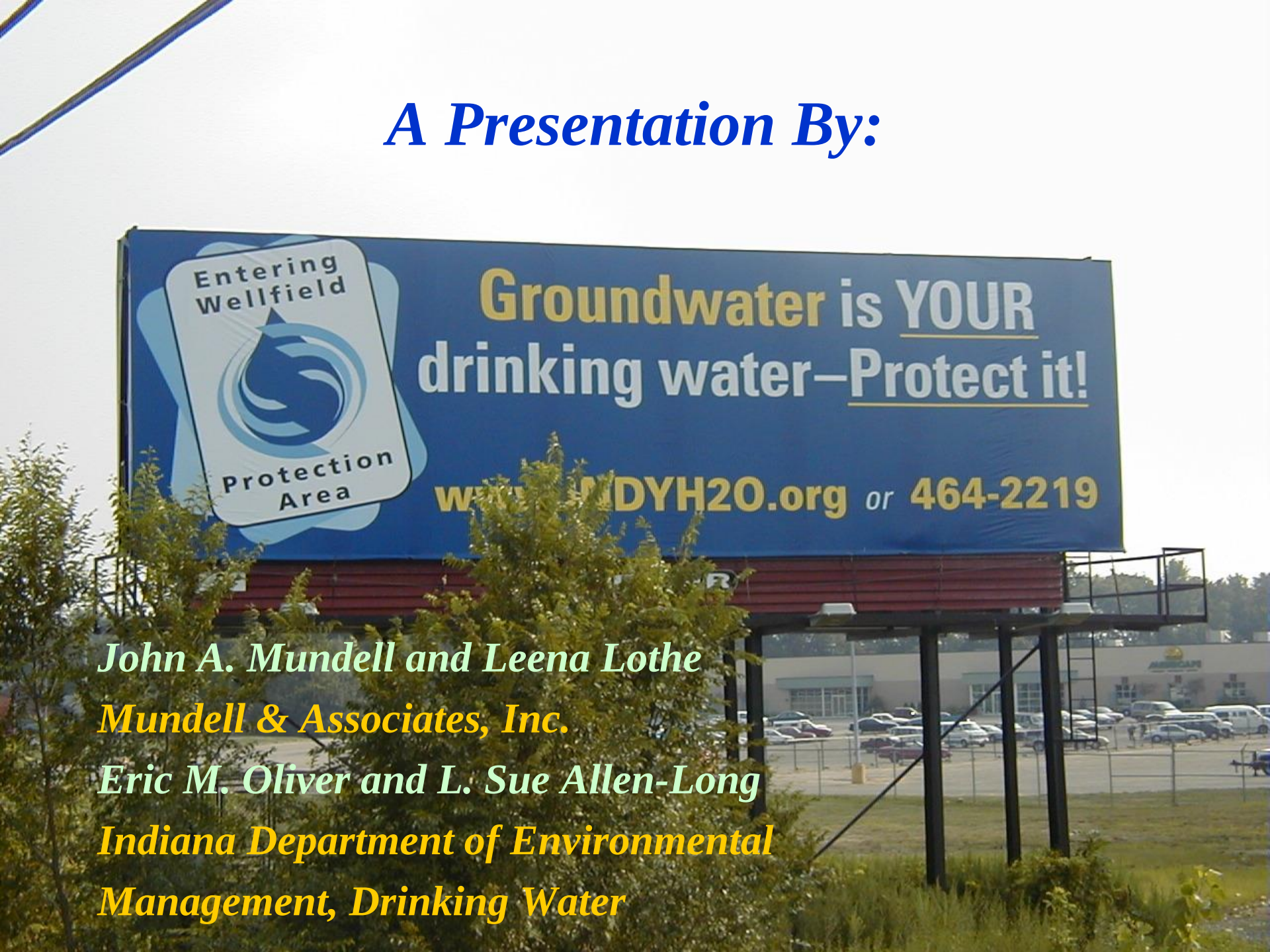


Aquifer Vulnerability Analysis: A Valuable Source Water Assessment Tool

2004 National Groundwater Association Conference and Exposition

December 13, 2004

A Presentation By:



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Indiana Department of Environmental Management, Drinking Water

Presentation Objectives

- Demonstrate the rationale behind the aquifer vulnerability assessment of wellhead areas
- Present a recent protocol developed and employed to assess aquifer vulnerability
- Provide example aquifer vulnerability assessments of two water supply systems

Wellhead Protection and Source Water Assessment

Wellhead Protection Philosophy:

- Land use can impact groundwater quality
- Managing contaminant sources minimizes potential impacts
- Prevention is less costly than treatment

Wellhead Protection and Source Water Assessment

Objective: Develop a flexible semi-quantitative approach that evaluates relative aquifer vulnerability for all water supply systems in the State of Indiana to allow the State to allocate resources to best manage the most vulnerable systems.

Source Water Protection Outreach

- By determining the areas most vulnerable to ground water contamination, the State will be able to focus its resources into these more susceptible areas.
  - Enhance community source water protection plans.
  - Target outreach materials and education.
  - Increase source water sampling frequency
  - Awareness of other State programs (IDEM, IDOT, IDNR).

Aquifer Vulnerability Protocol

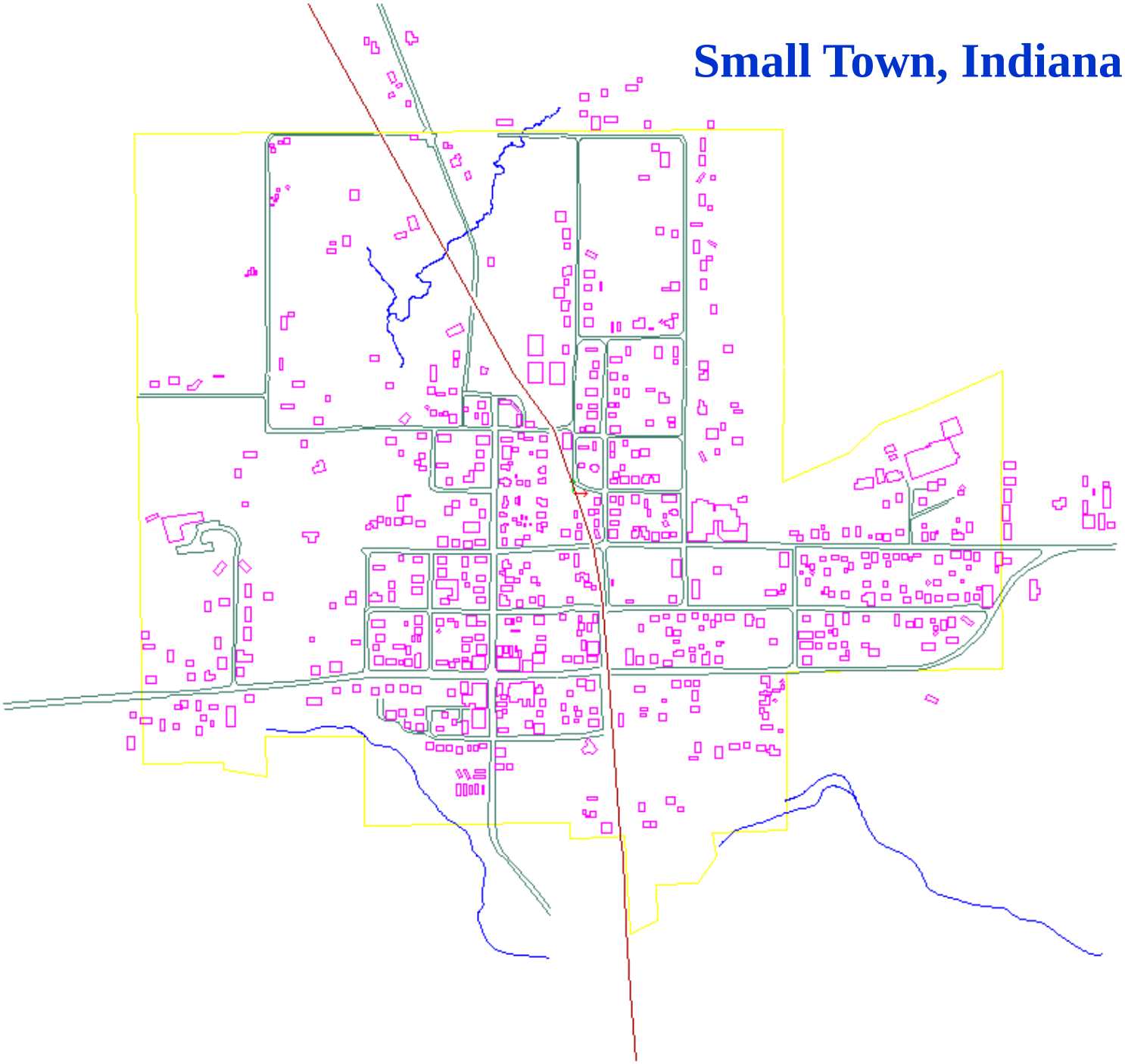
The vulnerability analysis can be conducted considering the following wellhead factors:

1. ***Hydrologic and hydrogeologic conditions***: The degree of protection from fine-grained geologic barriers above the pumping well screen (i.e., the presence/absence and thickness of fine-grained sediments).
2. ***Potential sources of contaminants (PSCs)***: number (and proximity) of PSCs within the delineated wellhead area (determined herein to be within the 5-year time of travel (TOT) zone)

Aquifer Vulnerability Protocol

3. ***Categories/types of contaminants***: distribution of type of contaminant source classifications within the delineated area.

Small Town, Indiana



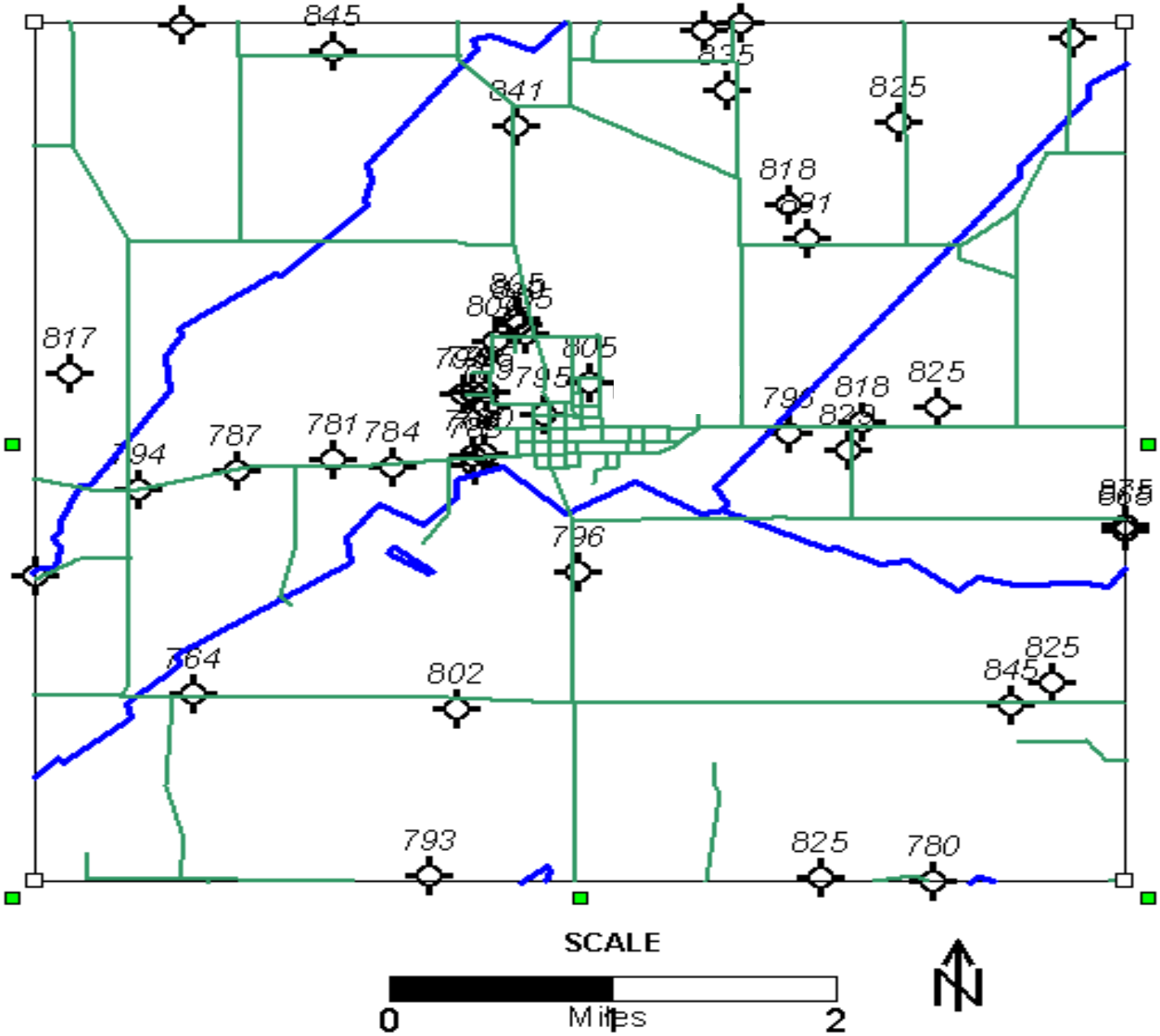
System Development for Aquifer Vulnerability Evaluation:

***Step 1*:** Geological and hydrogeological data review to evaluate the distribution and thickness of geologic barriers above the supply well screens (factor 1).

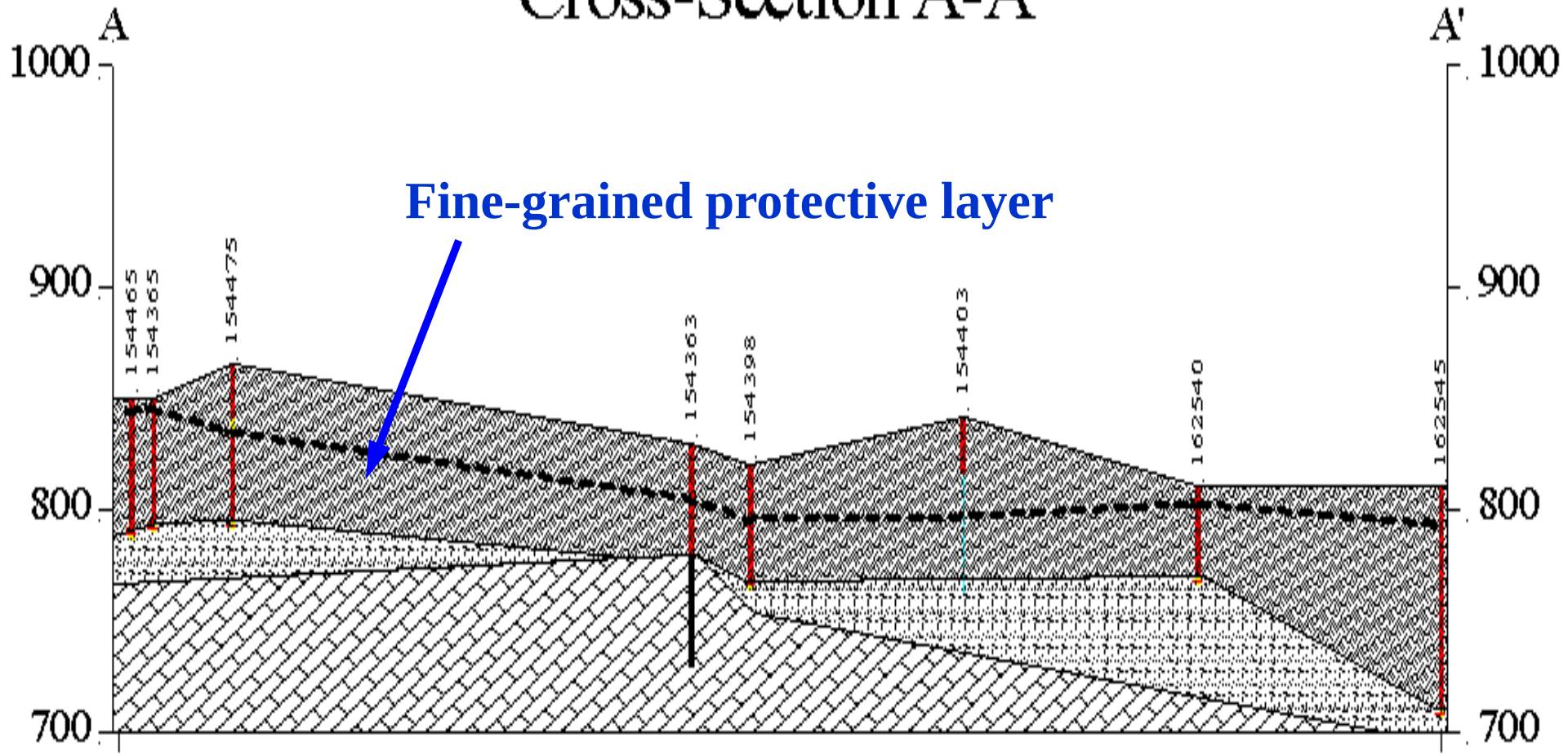
***Step 2*:** PSC inventories, landuse and PSC maps review, for estimating the number and proximity of the PSC (factor 2)

***Step 3*:** Review of PSC inventories specifically for assessing the categories of contaminants (factor 3) and rank the contaminant categories.

Geologic and Hydrogeologic Review



Cross-Section A-A'



BEDROCK

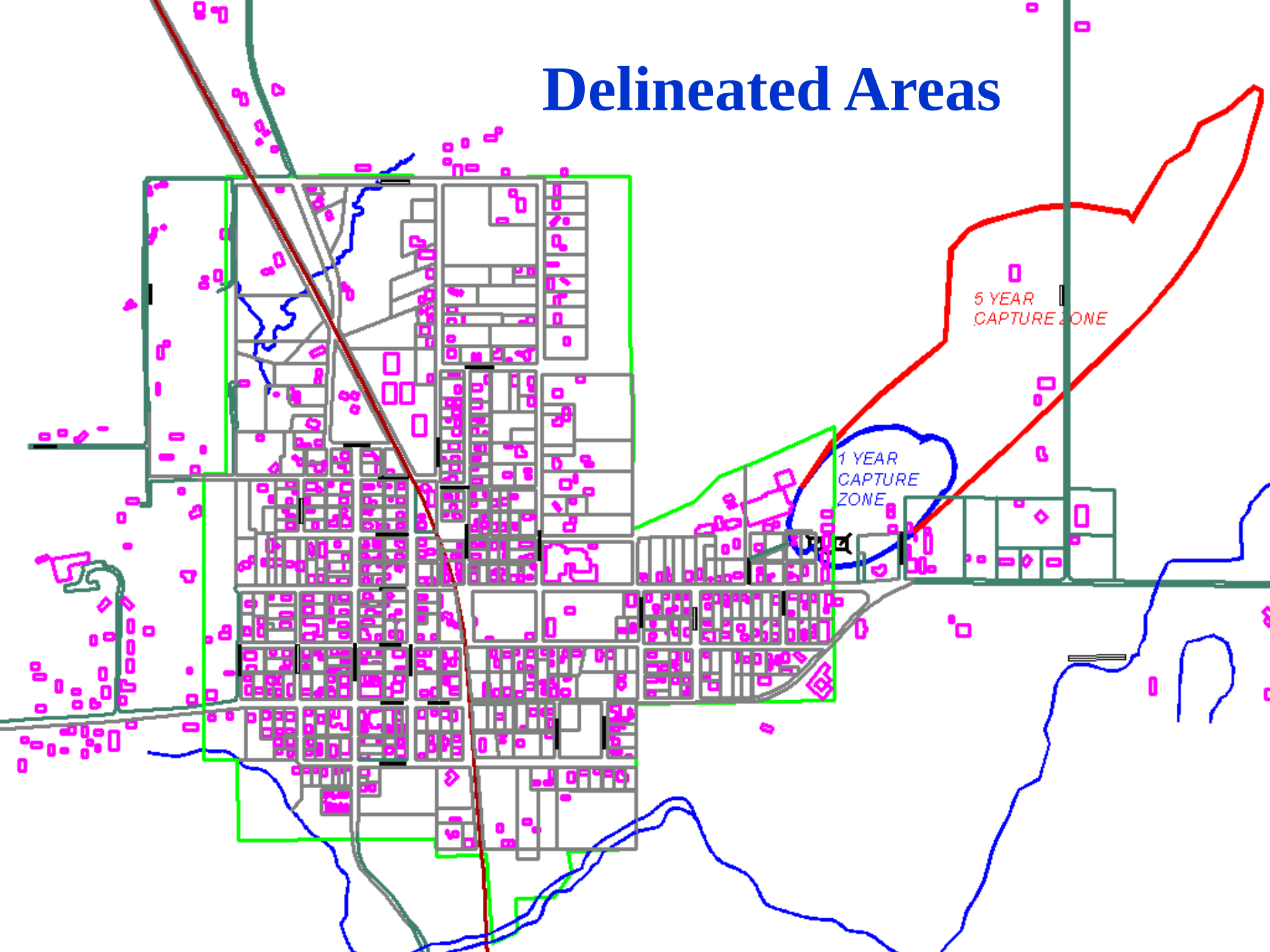
CLAY

SAND/GRAVEL

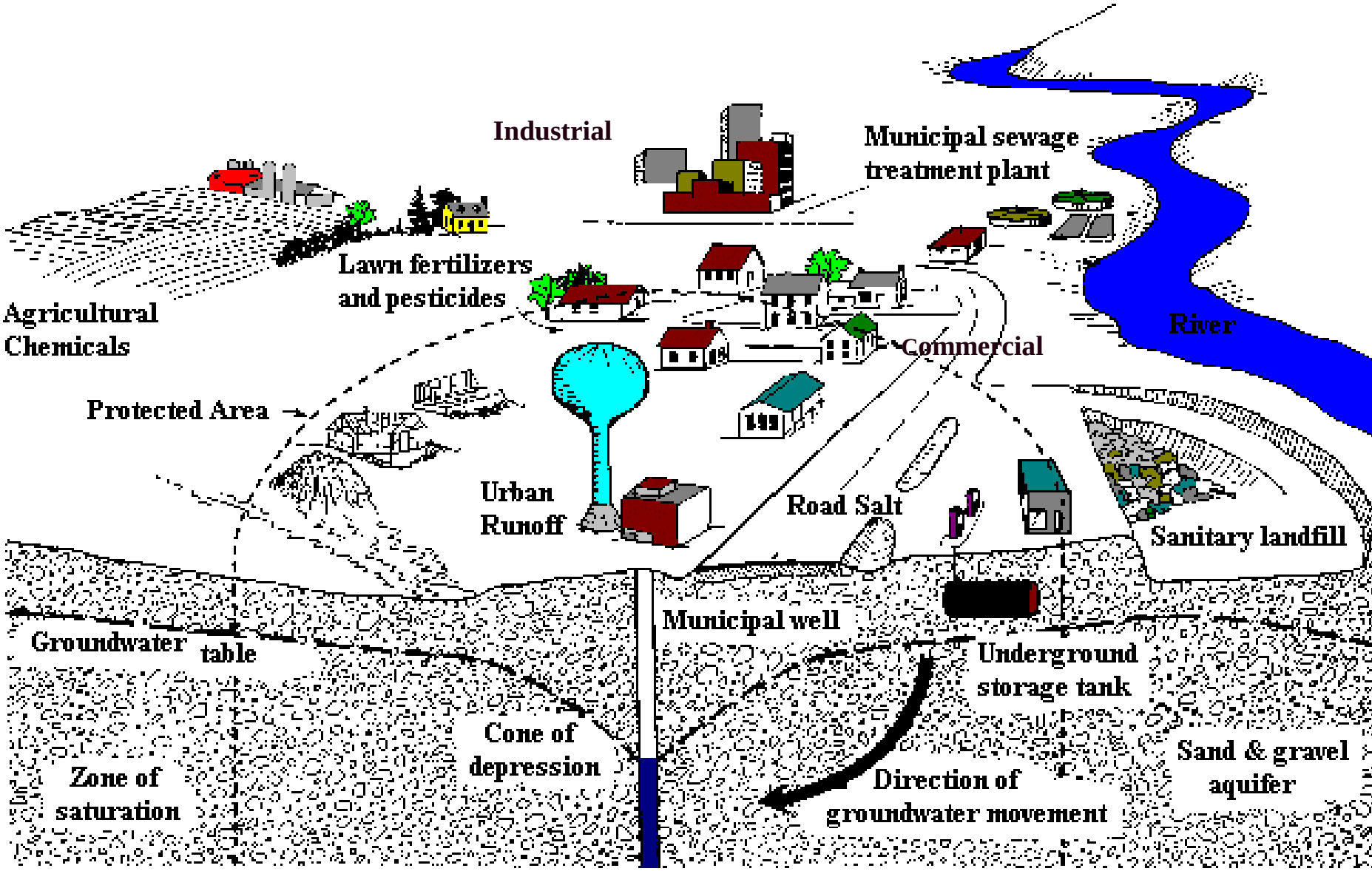
Section length: 25985 feet
Vertical Exaggeration: 25X

Section Location:
UTM 518241 4421917 (left)
UTM 516143 4414279 (right)
Selection width: 1500 ft

Delineated Areas



Contamination Sources



From Inventorying Contaminant Sources, Wisconsin DNR, 2000

Contaminant Categories/Types and Ranking

- Industrial (1)
- Commercial (2)
- Waste Management (3)
- Agricultural (4)
- Residential (5)

Contaminant Categories/Types and Ranking

Industrial (1)	Commercial (2)
Asphalt Plants	Airports
Chemical manufacture, warehousing	Auto repair shops
Electrical and electronic products and manufacturing	Boat yards
Electroplating and metal fabrication	Construction areas
Foundaries	Car washes
Machine and metal working shops	Cemeteries
Manufacturing and distribution of cleaning supplies	Dry cleaning establishments
Mining	Educational institutions (e.g. labs, lawns and chemical storage areas
Petroleum production and storage and distribution centers	Gas stations
Pipelines (e.g. oil, gas, coal, slurry)	Golf courses (chemical application)
Septage lagoons and sludge	Jewelry and metal plating
Storage Tanks (above-ground, below-ground,underground)	Laundromats
Toxic and hazardous spills	Medical Institutions
Wells-operarting and abandoned (e.g. oil, gas, water supply, injection, monitoring and exploration)	Paint shops
Wood preserving facilities	Photography establishments/printers
	Railroad tracks and yards/maintenance
	Research laboratories
	Road deicing operations (e.g. road salt)
	Road maintenance depots
	Scrap and junkyards

Contaminant Categories/Types and Ranking

Waste Management (3)	Agricultural (4)	Residential (5)
Hazardous waste management units (e.g. landfills, land treatment areas, surface impondments, waste piles, incinerators, treatment tanks)	Animal burial areas	Fuel storage systems
Municipal Incinerators	Animal Feedlots	Furniture and wood strippers and refinishers
Municipal Landfills	Chemical application (e.g. pesticides, and fertilizers)	Household hazardous products
Municipal waste water and sewer lines	Chemical Storage Areas	Household lawns (chemical application)
Open burning sites	Irrigation	Septic systems, cesspools, water softeners
Recycling and reduction facilities	Manure spreading and pits	Sewer/Septic Lines
Stormwater drains, retention basins, transfer stations		Swimming pools (e.g. chlorine)
State Confined Feeding Animal Operation (CAFO)		

System Development for Aquifer Vulnerability Evaluation:

- ***Step 4***: Determine the aquifer vulnerability using the '*Aquifer Vulnerability Matrix*'. The matrix determines aquifer system susceptibility based on the local geology and the well's vulnerability to contamination based on the number, proximity and type of PSCs.

Aquifer Vulnerability Matrix

	Low Geologic Sensitivity	Moderate Geologic Sensitivity	High Geologic Sensitivity
Low Contaminant Vulnerability	BT > 30 feet PSCs = 0 - 5 CT = 4, 5 (AVI = 0)	BT = 15 - 30 feet PSCs = 0 - 5 CT = 4, 5	BT = 0 - 15 feet PSCs = 0 - 5 CT = 4, 5
Moderate Contaminant Vulnerability	BT > 30 feet PSCs = 5 - 20 CT = 2, 3	BT = 15 - 30 feet PSCs = 5 - 20 CT = 2, 3	BT = 0 - 15 feet PSCs = 5 - 20 CT = 2, 3
High Contaminant Vulnerability	BT > 30 feet PSCs > 20 CT = 1	BT = 15 - 30 feet PSCs > 20 CT = 1	BT = 0 - 15 feet PSCs > 20 CT = 1 (AVI = 1)

Notes:

BT = Barrier Thickness, thickness ranges selected based on confidence in level of protection.
PSCs = Number of potential contaminant sources in the 5-year TOT zone.
CT = Contaminant Type (Category 1, 2, 3, 4 or 5 in Table 1)

Barrier thickness ranges selected based on confidence in barrier distribution and effectiveness. The PSC number ranges were selected based on calcuated average (mean) and standard deviation of number of PSCs observed in the 5-yr TOT zones provided in the WHPPs.

Aquifer Vulnerability Matrix

- The matrix illustrates that 'low geologic sensitivity' (BT > 30 feet) and 'low contaminant vulnerability' (PSCs = 0 to 5 and CT = 4,5) reflect very low/no aquifer vulnerability. (AVI = 0)
- Similarly 'high geologic sensitivity' (BT = 0 to 15 feet) and 'high contaminant vulnerability' (PSCs > 20 and CT = 1) reflect high aquifer vulnerability. (AVI = 1)

Aquifer Vulnerability Matrix

- The matrix demonstrates a gradient of increasing aquifer vulnerability from the top left hand cell of the matrix (AVI = 0) towards the bottom right hand cell (AVI = 1), and provides an effective means to summarize vulnerability assessments.

Aquifer Vulnerability Matrix

	Low Geologic Sensitivity	Moderate Geologic Sensitivity	High Geologic Sensitivity
Low Contaminant Vulnerability	BT > 30 feet PSCs = 0 - 5 CT = 4, 5 (AVI = 0)	BT = 15 - 30 feet PSCs = 0 - 5 CT = 4, 5	BT = 0 - 15 feet PSCs = 0 - 5 CT = 4, 5
Moderate Contaminant Vulnerability	BT > 30 feet PSCs = 5 - 20 CT = 2, 3	BT = 15 - 30 feet PSCs = 5 - 20 CT = 2, 3	BT = 0 - 15 feet PSCs = 5 - 20 CT = 2, 3
High Contaminant Vulnerability	BT > 30 feet PSCs > 20 CT = 1	BT = 15 - 30 feet PSCs > 20 CT = 1	BT = 0 - 15 feet PSCs > 20 CT = 1 (AVI = 1)

Notes:

BT = Barrier Thickness, thickness ranges selected based on confidence in level of protection.
PSCs = Number of potential contaminant sources in the 5-year TOT zone.
CT = Contaminant Type (Category 1, 2, 3, 4 or 5 in Table 1)

Barrier thickness ranges selected based on confidence in barrier distribution and effectiveness. The PSC number ranges were selected based on calcuated average (mean) and standard deviation of number of PSCs observed in the 5-yr TOT zones provided in the WHPPs.

Aquifer Vulnerability Index (AVI)

- AVI relates to the geologic, hydrogeologic and pollutant source conditions present in the wellfield.
- Provides a '*relative*' ranking scheme for comparing differing water supplies.
- Allows flexibility in the weighting of factors that affect the aquifer vulnerability.

Aquifer Vulnerability Index

$$AVI = \alpha_1 W_1 + \alpha_2 W_2 + \alpha_3 W_3$$

where:

Geologic Sensitivity Factor = W_1

PSC No. Factor = W_2

PSC Type Factor = W_3

Weighting Factor for geologic barrier, α_1

Weighting Factor for PSC No., α_2

Weighting Factor for PSC Type, α_3

Aquifer Vulnerability Index

Geologic Sensitivity Factor, W_1

where:

$W_1 = 0$	BT	> 30 ft
$W_1 = 0.5$	BT	= 15 to 30 ft
$W_1 = 1.0$	BT	< 15 ft

Aquifer Vulnerability Index

PSC No. Factor, W_2

where:

$W_2 = 0$	PSC No. = 0 to 5
$W_2 = 0.5$	PSCs No. = 5 to 20
$W_2 = 1.0$	PSCs No. > 20

Aquifer Vulnerability Index

PSC Type Factor, W_3

where:

$W_3 = 0$ CT = 4, 5 (agricultural, residential)

$W_3 = 0.5$ CT = 2, 3 (commercial, waste mgmt.)

$W_3 = 1.0$ CT = 1 (industrial)

Weighting Factor Assignment

- A thick geologic barrier might be given more weight as compared to no/low number of PSCs, since the number of PSCs have the potential to change with time. A thick geologic barrier indicates a lower aquifer vulnerability irrespective of the number or type of PSCs.

- On the other hand, a thin or no barrier thickness indicates a high aquifer vulnerability, even if there is a low number of PSCs.

Weighting Factors used:

For the protocol recommended, the following weights were used:

- Weighting Factor for geologic barrier, $\alpha_1 = 0.6$
- Weighting Factor for PSC No., $\alpha_2 = 0.2$
- Weighting Factor for PSC Type, $\alpha_3 = 0.2$

AVI Calculations-The Modus Operandi

Aquifer Vulnerability Index (AVI) Calculations:

(Spreadsheet Example: for a geologic barrier of 15 feet, No. of PSCs = 9, and type of PSC = agricultural)

Given:

Geologic Sensitivity - Barrier Characterization

Geologic Factor, W_1 =			**0**	INPUT
	note:	W_1 =	0	(BT > 30 feet)
		W_1 =	0.5	(BT = 15 - 30 feet)
		W_1 =	1	(BT = 0 - 15 feet)

Potential Contaminant Sources Number

PSC No. Factor, W_2 =			**1**	INPUT
	note:	W_2 =	0	(PSC No. = 0 - 5)
		W_2 =	0.5	(PSC No. = 5 - 20)
		W_2 =	1	(PSC No. > 20)

(Note: Count all residential sewers as contributing to PSC No. = 1; count all residential septics/sewers as contributing to PSC No.= 3)

Potential Contaminant Sources Characterization

PSC Type Factor, W_3 =			**1**	INPUT
(Refer to Table 1)	note:	W_3 =	0	(CT = 4, 5; agricultural, residential)
		W_3 =	0.5	(CT = 2, 3; commercial, waste management)
		W_3 =	1	(CT = 1; industrial)

AVI Calculations-The Modus Operandi

Assumptions: Weighting Factor for geologic barrier, α_1 = **0.6** INPUT

(Note: A thick geologic barrier is given more weightage as compared to no/low number of PSCs, since PSC have a potential to increase with time.)

Weighting Factor for PSC No., α_2 = **0.2** INPUT

Weighting Factor for PSC Type, α_3 = **0.2** INPUT

Calculations:

Aquifer Vulnerability Index, AVI = $(\alpha_1 W_1 + \alpha 2 W_2 + \alpha 3 W_3)$

AVI = 0.40 OUTPUT

Notes:

BT = Barrier Thickness

PSC No. = Number of potential contaminant sources in the 5-year TOT zone

CT= Contaminant Type (category)

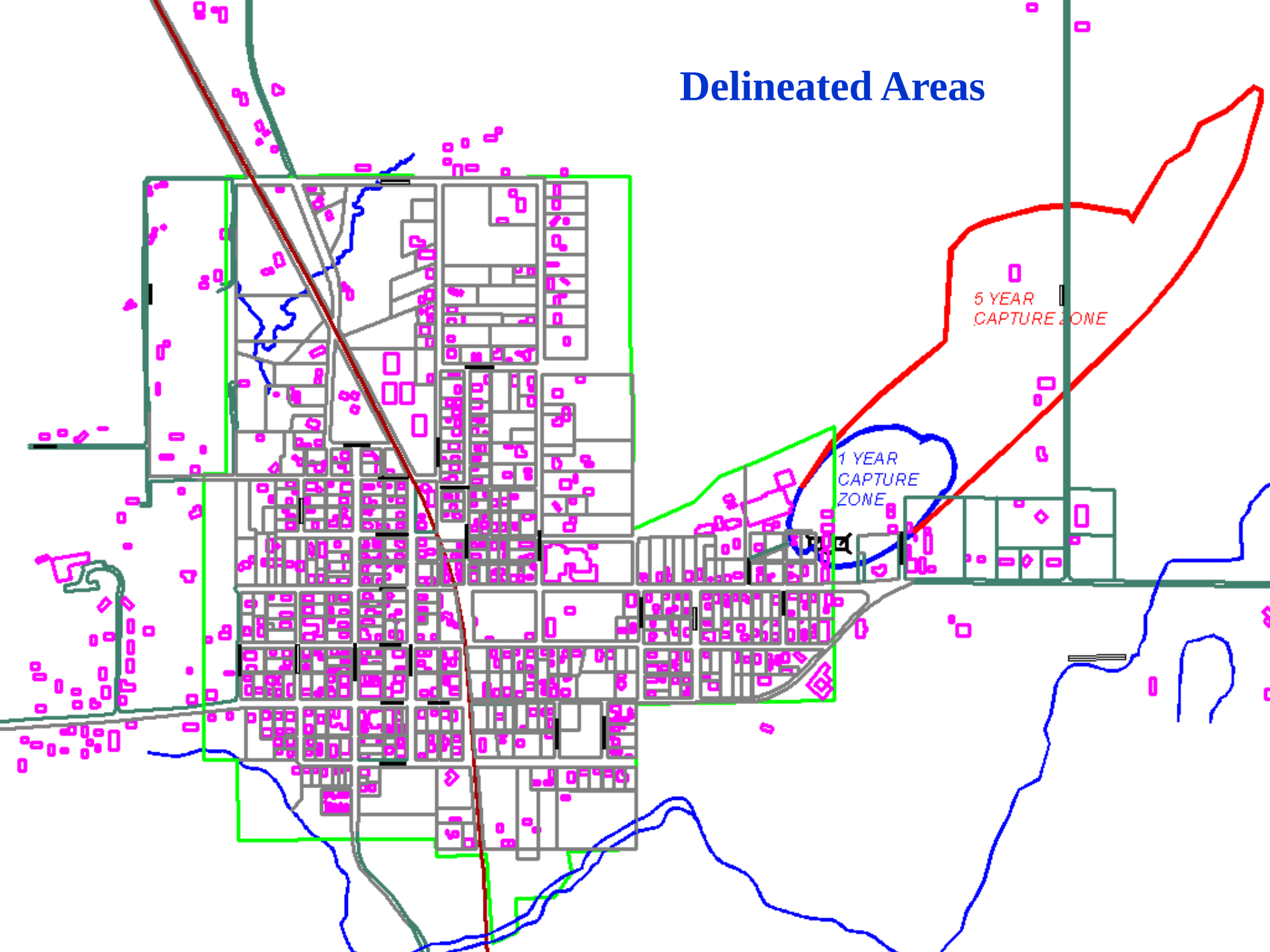
Aquifer Vulnerability Classification

AVI Range	Aquifer Vulnerability
0 < AVI < 0.25	Low
0.25 < AVI < 0.75	Moderate
0.75 < AVI < 1	High

Example Aquifer Vulnerability Calculations

Town A has ***35 to 40 feet*** of clay above the production well screened interval, and ***2*** potential sources of contamination (PSCs) within the 5-year time of travel (TOT) zone. The type of PSCs are predominantly ***industrial,*** and the town is on ***septic systems.***

Delineated Areas



1. As per the geologic sensitivity-barrier characterization, in this case, the geologic factor '***W1' = 0*** since the Barrier Thickness, BT > 30 feet.

2. The PSC No. Factor '***W2***'= ***0*** , since PSC No. = 0 to 5. Note that all residential sewers count as contributing to PSC No. = 1.

3. The PSC Type Factor, ***'W3' = 1*** , since CT = 1; industrial.

AVI = (α1 W1 + α2 W2 + α3 W3) = (0.6(0) + 0.2(0) + 0.2(1) = ***0.2***. This categorizes the system as having a ***'low'*** vulnerability.

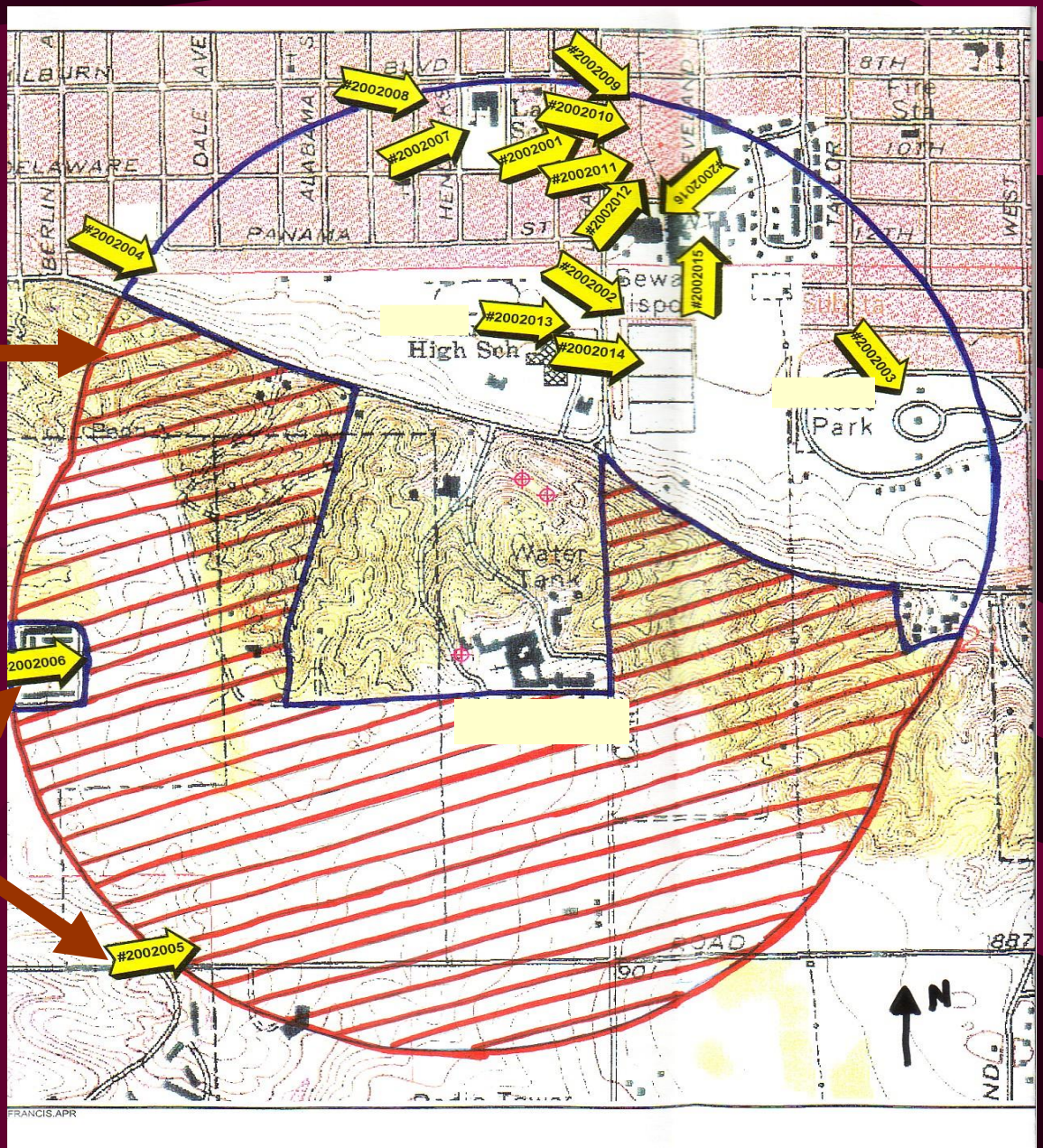
Example Aquifer Vulnerability Calculations

Town B has ***0 feet*** of overlying clay, and ***16*** PSCs within the 5-year TOT zone. The type of PSCs are predominantly ***industrial,*** and the town is on a ***sewer system.***

Town B Wellhead Area

Wellhead Protection Area (5 year TOT zone) Boundary

Potential Contamination Sources



1. As per the geologic sensitivity-barrier characterization, the geologic factor:

   ‘***W1’ = 1***, since BT = 0 to 15 feet.

2. The PSC No. Factor :

   ‘***W2***’= ***0.5*** , since PSC No. = 5 to 20.

3. The PSC Type Factor:

   ‘W3’ = 1 , since CT = 1; industrial.

AVI = (0.6)(1) + 0.2 (0.5) + 0.2 (1) = ***0.9***.

Therefore, the system is rated as one with a ‘***high***’ vulnerability.

Conclusions

- The proposed aquifer vulnerability ranking protocol has proven to be an effective, flexible tool for providing an objective, semi-quantitative relative ranking system for utility systems using limited data available in most wellfield protection plans.
- The use of both an *Aquifer Vulnerability Matrix* and an *Aquifer Vulnerability Index (AVI)* allows a technically sound framework within which wellfield ranking can help guide the local decision-making of governmental agencies in developing strategies for the management of the public water supply.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