Potential Environmental Impact of Produced Water

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Topics for Discussion

- Background on produced water
- Potential environmental impacts caused by produced water
- Evaluation of potential for impacts (risk assessment)
- Example of how good science overcame the perception of an environmental impact

What is Produced Water?

- Water that comes to the surface with oil and gas
- Contains many chemical constituents
  - Salt content (salinity, total dissolved solids [TDS], electrical conductivity)
  - Oil and grease
    - Composite of many hydrocarbons and other organic materials
  - Toxicity from various natural inorganic and organic compounds or chemical additives
  - NORM

Produced Water Volume

- Largest volume waste stream from oil and gas production
  - Worldwide estimate – 77 billion bbl/year (2003 SPE paper)
  - U.S. – 21 billion bbl/year (Clark and Veil 2009)
    - ~57 million bbl/day or 2.4 billion gallons/day
    - Metric: 3.3 billion m^3/year or 9.2 million m^3/day
- Ratio of water-to-oil
  - World-wide estimate – 2:1 to 3:1
  - U.S. estimate – 5:1 to 8:1
    - with more complete data sets that include TX and OK data, this would be >10:1

Clark and Veil 2009 can be downloaded at:
http://www.veilenvironmental.com/produced_water.html

Potential Adverse Impacts of Produced Water

- Different impacts at different locations
- Depends on the level of key chemical constituents and the nature of the water, soil, or other substrate into/onto which the produced water is released
- Not all impacts are bad
  - There are beneficial uses for produced water too

Potential Pathways for Produced Water to Impact the Environment

Spills and Leaks

Discharge to Surface Water

Underground Injection

Air Emissions

- The main constituent of produced water that causes impacts is salt
- Other constituents can create problems in certain settings

Spills and Leaks

- Salt can contaminate soils near wellheads, pipelines, and other facilities
  - Kills plants
  - Damages soils to impact future plant growth
- Large spills can move into surface water bodies
  - Salt problems in freshwater
  - Toxic compounds and oil and grease can damage aquatic life
- Leakage from tanks or impoundments can soak into the ground and enter groundwater
  - In addition to harming soils, large releases of produced water may soak deep into the ground and enter sources of drinking water
    - Impacts from salt, oil and grease, and from toxics

Discharge to Surface Water

- Discharges of salty produced water into fresh water bodies will cause damage to aquatic animals and plants
  - Discharge of salty water to the ocean does not cause salt-related harm
- Discharges of oil and grease and toxic chemicals can cause damage in both fresh and salt water
- Discharges of produced water are authorized by a regulatory agency through permits

Underground Injection

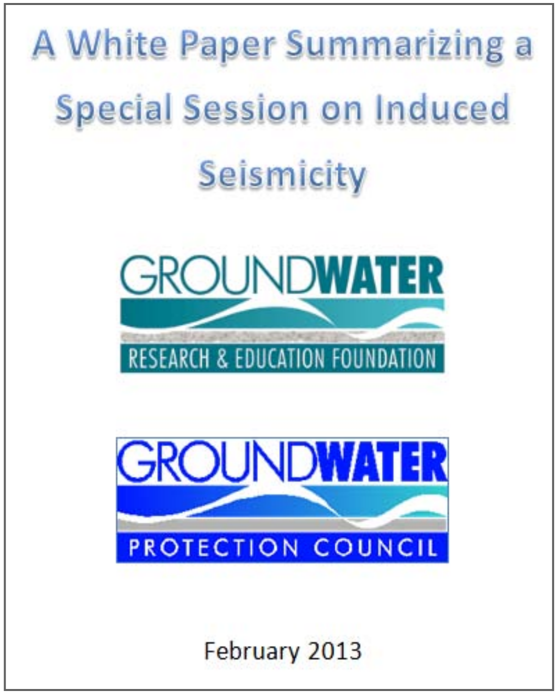
- Most onshore produced water is injected – this is generally safe
- Need to check the chemical compatibility of the injected produced water with the chemicals already found in the rock and the ground water
  - Incompatibility of the chemicals can cause precipitates to form that block pores and require additional injection pressure
  - Potential microbial problems can occur in the formation that lead to hydrogen sulfide generation

Underground Injection (2)

- Need to construct injection wells properly
  - Poor construction and bad cementing can create pathways for injected produced water to move to the surface or to a drinking water zone
  - Exceedance of operating pressure requirements can cause similar problems
- Extended injection can lead to seismic activities
  - Very low level seismic is common and does not pose any problems
- A small subset of injection wells are sited at locations with unexpected geological features
  - On occasion, these can cause seismic activities that can be felt at the surface
- In the U.S., 150,000 to 200,000 injection wells operate each day
  - Only a tiny proportion of these cause noticeable seismic activity

References on Induced Seismicity

- Veil, 2013, “A White Paper Summarizing a Special Session on Induced Seismicity” **http://www.veilenvironmental.com/publications/pw/white_paper_on_induced_seismicity.pdf**
- National Academy of Sciences, 2012, “Induced Seismicity Potential in Energy Technologies” **http://www.nap.edu/catalog.php?record_id=13355**.



A White Paper Summarizing a Special Session on Induced Seismicity

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Induced Seismicity Potential in Energy Technologies

Committee on Induced Seismicity Potential in Energy Technologies
Committee on Earth Resources
Committee on Geological and Geotechnical Engineering
Committee on Seismology and Geodynamics
Board on Earth Sciences and Resources
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Air Emissions

- Movement and treatment of produced water requires much power (pumps, engines, etc.)
  - Operation of this type of equipment generates air emissions, including CO_2
- Evaporation pits and ponds or mechanical evaporators can create plumes of vapor that deposit on the ground down-wind of the site
  - The salty deposits can harm plants and soil

Source: BC Technologies

Principles of Risk Assessment as Applied to Produced Water Management

Basics of Risk Assessment

- Risk assessment considers the hazard posed by an activity and the chemicals involved, as well as the likelihood of an event or exposure to humans or other animals that could cause harm
- Risk assessment involves 4 integrated tasks
  - Hazard identification
  - Exposure assessment
  - Toxicity (dose-response) assessment
  - Risk characterization

Hazard Identification

- What chemicals are likely to be present in produced water?
  - Salt
  - Oil and grease
  - Metals
  - Organics
  - NORM
  - Nutrients
  - High temperature

- The presence of specific chemicals and their concentrations varies greatly from place-to-place and over time

Exposure Assessment

- Evaluate the specific produced water management activity
  - Potential for releases via spills, leaks, and other accidents
- Identify release mechanisms
  - Broken valves
  - Corroded pipes
  - Bad cement job on injection well
- Identify potential receptors
  - Surface water
  - Ground water
  - Soil
  - Animals
  - Plants
  - People

Exposure Assessment (2)

- Identify the proximity of the produced water management facility to potential exposure/contact locations
  - How far away are sensitive environmental settings or sensitive animal, plant, or human populations?
- Assess the likelihood of exposure
  - Chemical reactions in a water body or in ground water may change the form or properties of chemicals or can produce new chemicals
  - Adsorption or geochemical reactions may bind chemicals in formation (less available)
  - Dilution/dispersion
- Estimate magnitude of exposure
  - Estimate concentrations <u>at points of exposure</u>
  - Estimate quantity of each chemical taken in by receptors

Toxicity (Dose-Response) Assessment

- Water
  - Water quality criteria and standards
    - Acute (short term exposure)
    - Chronic (long-term exposure)
  - Drinking water standards
- Soil
  - Clean up standards based on plant requirements
  - Agricultural soil standards
- Human health safe exposure levels
  - Cancer
  - Other non-cancer health affects
  - Ingestion vs. inhalation vs. skin contact

Risk Characterization: Human Health

- Compare estimates of exposure levels to the target (“acceptable”) values
    - Considers the probability of a sensitive area receiving an exposure
    - Amount of exposure
    - Duration of exposure

Example of Risk Analysis Using A Decision Tree to Evaluate Potential Hazard

Risk Analysis for Class I Injection Well (used to inject hazardous wastes deep underground)

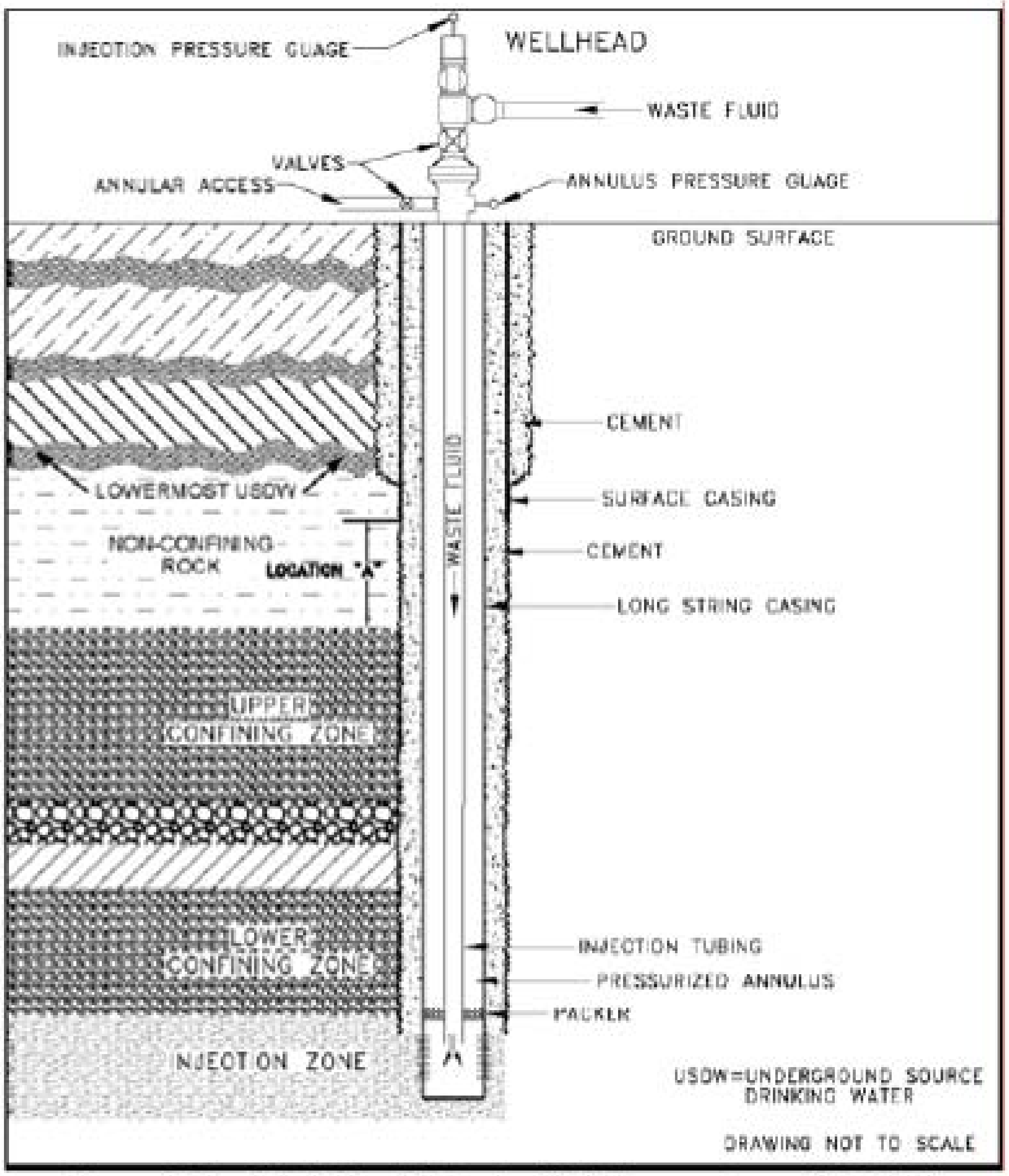
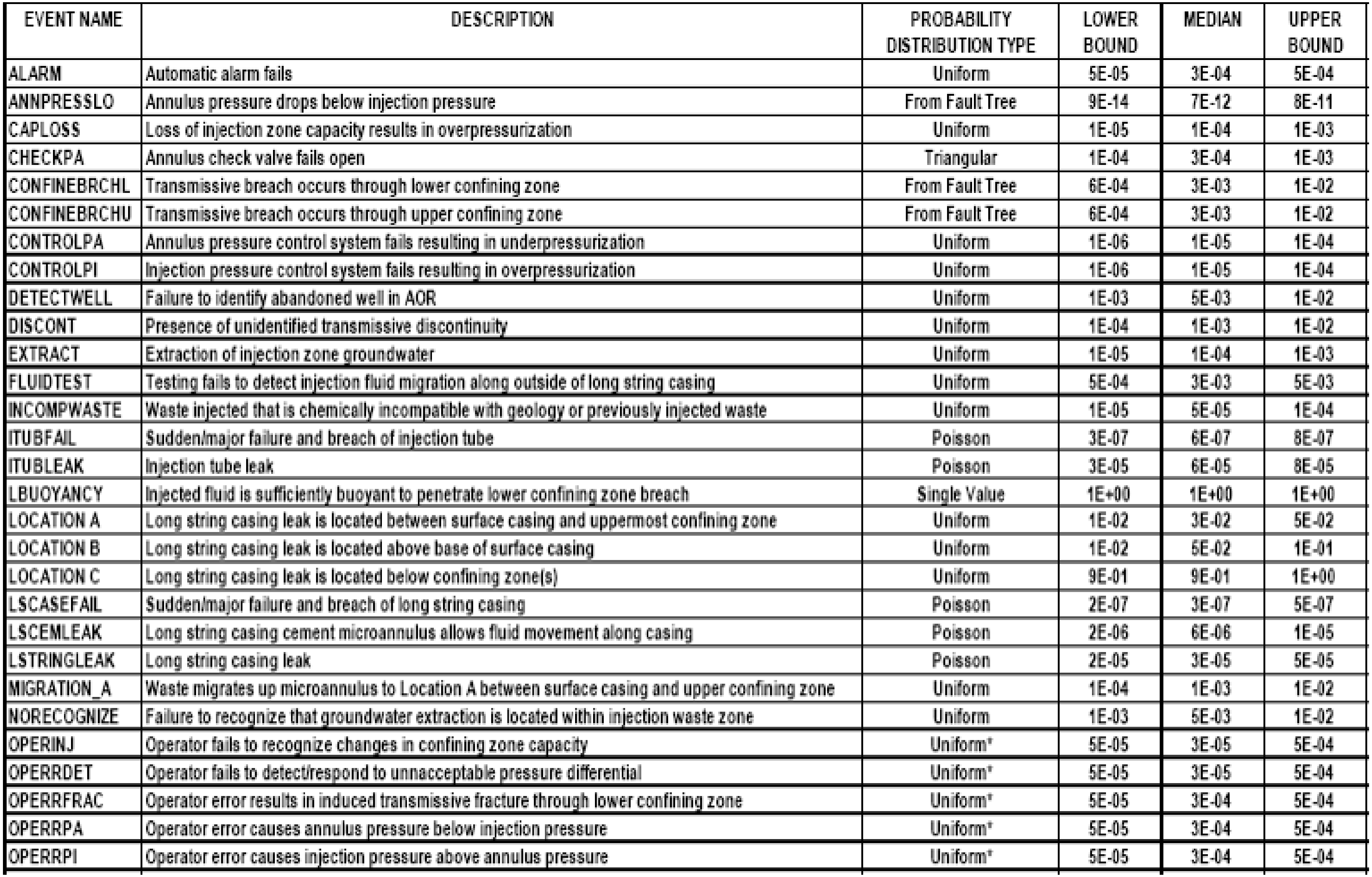


Figure 1 Simplified Class I Injection Well System Assumed for PRA

Source: William Rish, Hull and Associates, paper presented at 2003 Underground Injection Symposium

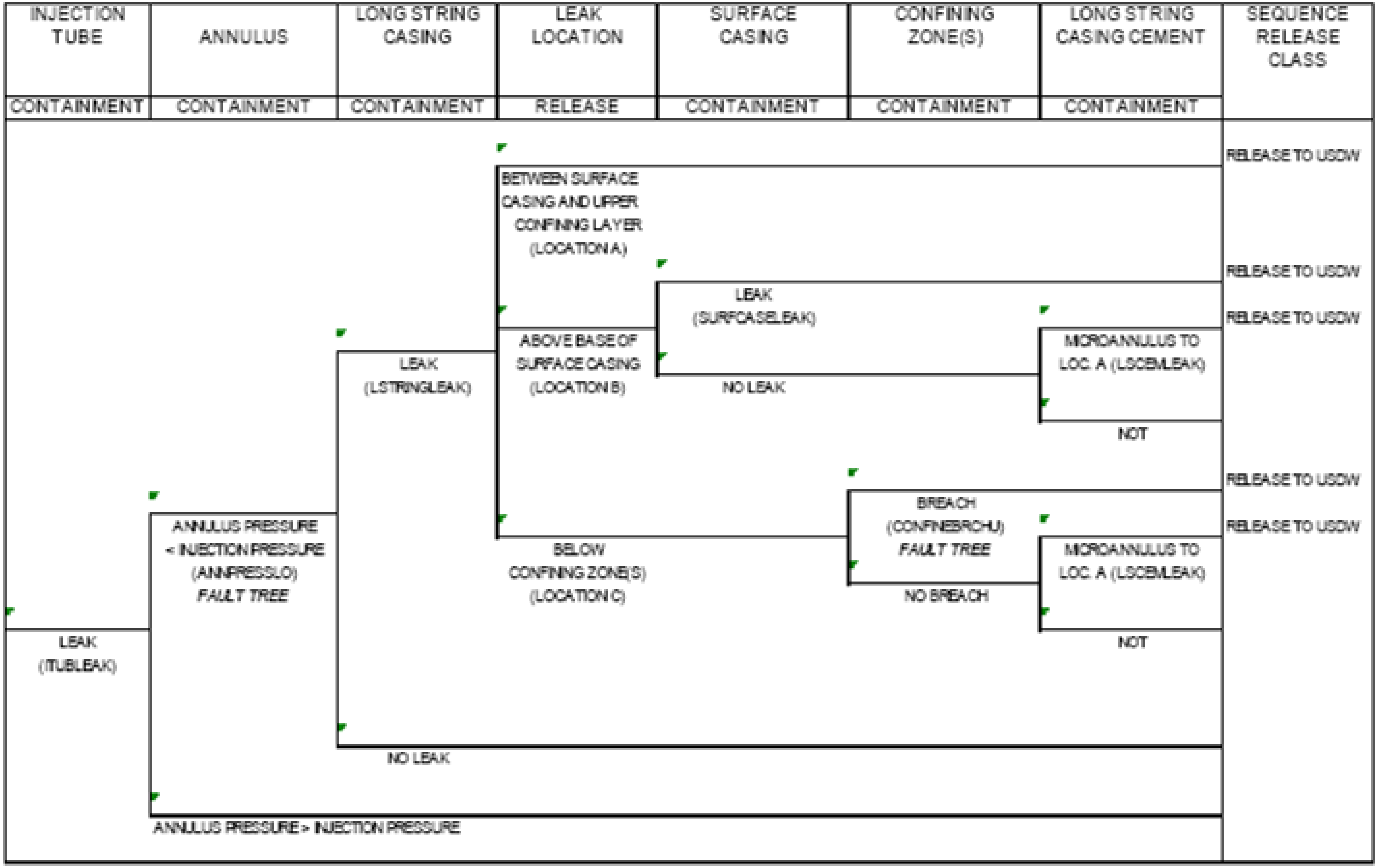
Event Probability Distributions -Class I Well Risk Analysis



EVENT NAME	DESCRIPTION	PROBABILITY DISTRIBUTION TYPE	LOWER BOUND	MEDIAN	UPPER BOUND
ALARM	Automatic alarm fails	Uniform	5E-05	3E-04	5E-04
ANNPRESSLO	Annulus pressure drops below injection pressure	From Fault Tree	9E-14	7E-12	8E-11
CAPLOSS	Loss of injection zone capacity results in overpressurization	Uniform	1E-05	1E-04	1E-03
CHECKPA	Annulus check valve fails open	Triangular	1E-04	3E-04	1E-03
CONFINEBRCHL	Transmissive breach occurs through lower confining zone	From Fault Tree	6E-04	3E-03	1E-02
CONFINEBRCHU	Transmissive breach occurs through upper confining zone	From Fault Tree	6E-04	3E-03	1E-02
CONTROLPA	Annulus pressure control system fails resulting in underpressurization	Uniform	1E-06	1E-05	1E-04
CONTROLPI	Injection pressure control system fails resulting in overpressurization	Uniform	1E-06	1E-05	1E-04
DETECTWELL	Failure to identify abandoned well in AOR	Uniform	1E-03	5E-03	1E-02
DISCONT	Presence of unidentified transmissive discontinuity	Uniform	1E-04	1E-03	1E-02
EXTRACT	Extraction of injection zone groundwater	Uniform	1E-05	1E-04	1E-03
FLUIDTEST	Testing fails to detect injection fluid migration along outside of long string casing	Uniform	5E-04	3E-03	5E-03
INCOMPWASTE	Waste injected that is chemically incompatible with geology or previously injected waste	Uniform	1E-05	5E-05	1E-04
ITUBFAIL	Sudden/major failure and breach of injection tube	Poisson	3E-07	6E-07	8E-07
ITUBLEAK	Injection tube leak	Poisson	3E-05	6E-05	8E-05
LBUOYANCY	Injected fluid is sufficiently buoyant to penetrate lower confining zone breach	Single Value	1E+00	1E+00	1E+00
LOCATION A	Long string casing leak is located between surface casing and uppermost confining zone	Uniform	1E-02	3E-02	5E-02
LOCATION B	Long string casing leak is located above base of surface casing	Uniform	1E-02	5E-02	1E-01
LOCATION C	Long string casing leak is located below confining zone(s)	Uniform	9E-01	9E-01	1E+00
LSCASEFAIL	Sudden/major failure and breach of long string casing	Poisson	2E-07	3E-07	5E-07
LSCEMLEAK	Long string casing cement microannulus allows fluid movement along casing	Poisson	2E-06	6E-06	1E-05
LSTRINGLEAK	Long string casing leak	Poisson	2E-05	3E-05	5E-05
MIGRATION_A	Waste migrates up microannulus to Location A between surface casing and upper confining zone	Uniform	1E-04	1E-03	1E-02
NORECOGNIZE	Failure to recognize that groundwater extraction is located within injection waste zone	Uniform	1E-03	5E-03	1E-02
OPERINJ	Operator fails to recognize changes in confining zone capacity	Uniform*	5E-05	3E-05	5E-04
OPERRDET	Operator fails to detect/respond to unnacceptable pressure differential	Uniform*	5E-05	3E-05	5E-04
OPERRFRAC	Operator error results in induced transmissive fracture through lower confining zone	Uniform*	5E-05	3E-04	5E-04
OPERRPA	Operator error causes annulus pressure below injection pressure	Uniform*	5E-05	3E-04	5E-04
OPERRPI	Operator error causes injection pressure above annulus pressure	Uniform*	5E-05	3E-04	5E-04

Source: Rish 2003

Example of Event Tree for Class I Well Failure



Source: Rish 2003

Example of How Science Can Positively Influence a Regulatory Outcome

2004-2005 Study of Produced Water Discharges to the Gulf of Mexico Hypoxic Zone

- Each year, a large hypoxic zone (dissolved oxygen <2.0 mg/L) forms in the near-shore Gulf of Mexico
- Primary contribution is nutrient inputs from Mississippi River and Atchafalaya River
- Nutrients cause rapid growth of phytoplankton
- Later these die off and sink to the bottom where they are decomposed by microorganisms
  - This depletes the available oxygen

Data Source: N. Rabalais, LUMCON

Basis for Study

- No good data existed on the oxygen-demanding properties of produced water
- EPA did not want to continue produced water discharges indefinitely without having data and analysis to show the level of impact caused by the discharges
  - In other words, <u>EPA wanted to evaluate the risks to Gulf of Mexico water quality posed by produced water discharges</u>
- EPA issued a permit in late 2004 requiring a sampling program involving many platforms with the results being submitted by August 2005

Sample Design and Schedule

- Sampled 10% of approximately 500 discharges in the hypoxic zone
  - 16 platforms sampled three times
  - 34 platforms sampled one time
- Parameters tested

Measure Indirect Oxygen Demand

- **ammonia**
- **nitrate**
- **nitrite**
- **total Kjeldahl nitrogen (TKN)**
- **total phosphorus**
- **orthophosphate**

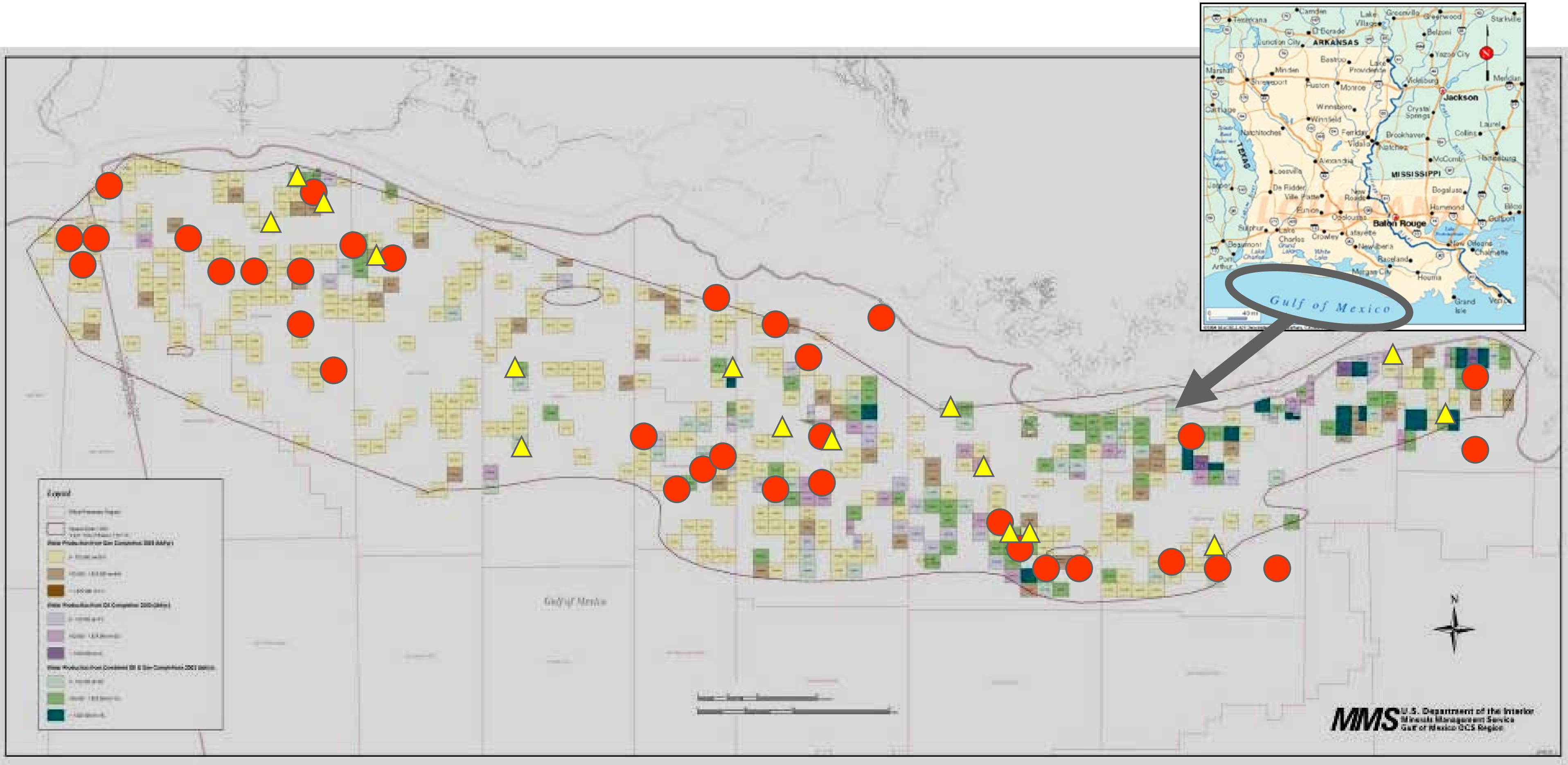
Measure Direct Oxygen Demand

- **BOD**
- **TOC**

Other Parameters

- **pH**
- **conductivity**
- **salinity**
- **temperature**

Location of Platforms Sampled for Hypoxic Zone Produced Water Study

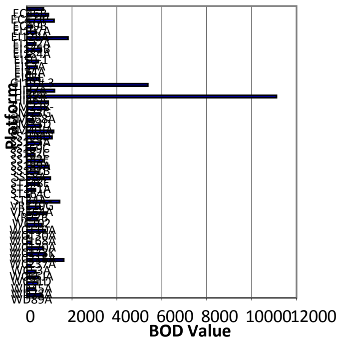


- ● Platforms sampled one time and selected at random
- △ Platforms sampled three times and selected based on discharge volume and type of hydrocarbon produced

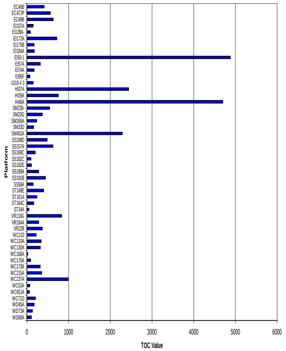
Summary of Analytical Data

Parameter	Mean	Median	Maximum	Minimum
BOD, mg/L	957	583	11,108	80
Dissolved BOD, mg/L	498	432	1,128	132
Suspended BOD, mg/L	76	57	146	16
TOC, mg/L	564	261	4,880	26
Dissolved TOC, mg/L	216	147	620	67
Suspended TOC, mg/L	32	13	127	5
Nitrate, mg/L	2.15	1.15	15.80	0.60
Nitrite, mg/L	0.05	0.05	0.06	0.05
Ammonia, mg/L	74	74	246	14
TKN, mg/L	83	81	216	17
Orthophosphate, mg/L	0.43	0.14	6.60	0.10
Total phosphorus, mg/L	0.71	0.28	7.90	0.10
Conductivity, umhos/cm	87,452	86,480	165,000	360
Salinity, ppt	100	84	251	0
Temperature, ^{o}C	38	32	80	20
pH, SU	6.29	6.50	7.25	1.77

Results from All Platforms



BOD



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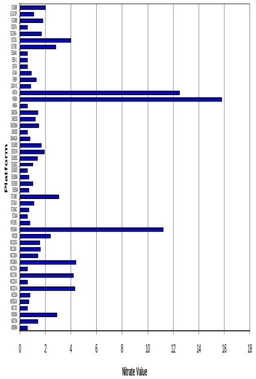
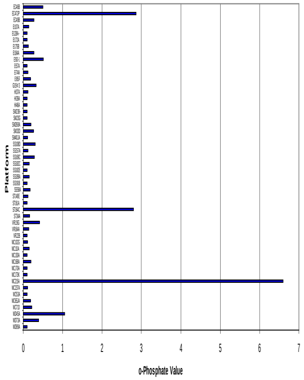
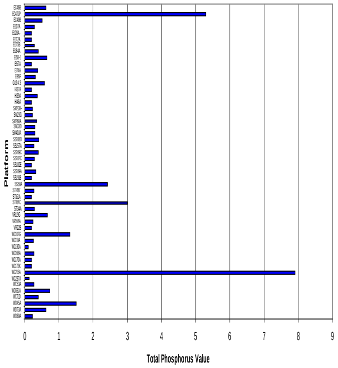


Nitrate



Orthophosphate



Total Phosphorus

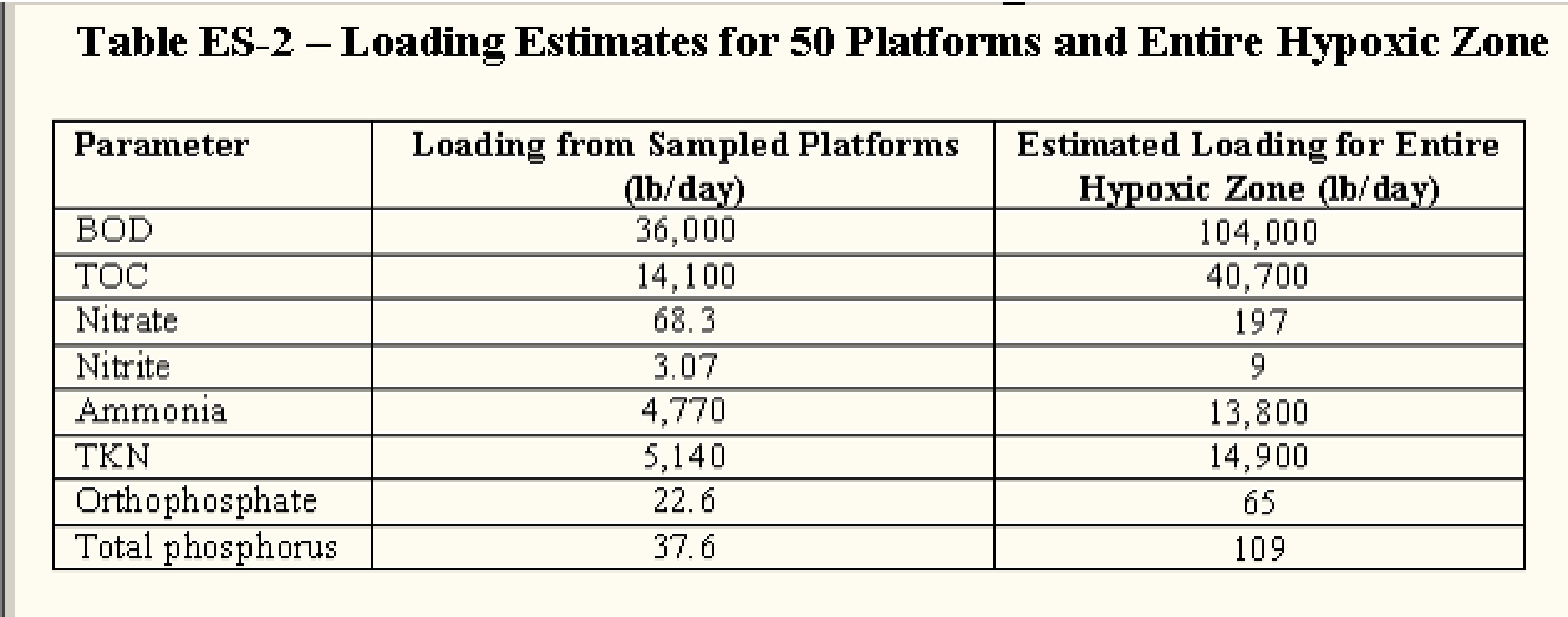


Table ES-2 – Loading Estimates for 50 Platforms and Entire Hypoxic Zone

Parameter	Loading from Sampled Platforms (lb/day)	Estimated Loading for Entire Hypoxic Zone (lb/day)
BOD	36,000	104,000
TOC	14,100	40,700
Nitrate	68.3	197
Nitrite	3.07	9
Ammonia	4,770	13,800
TKN	5,140	14,900
Orthophosphate	22.6	65
Total phosphorus	37.6	109

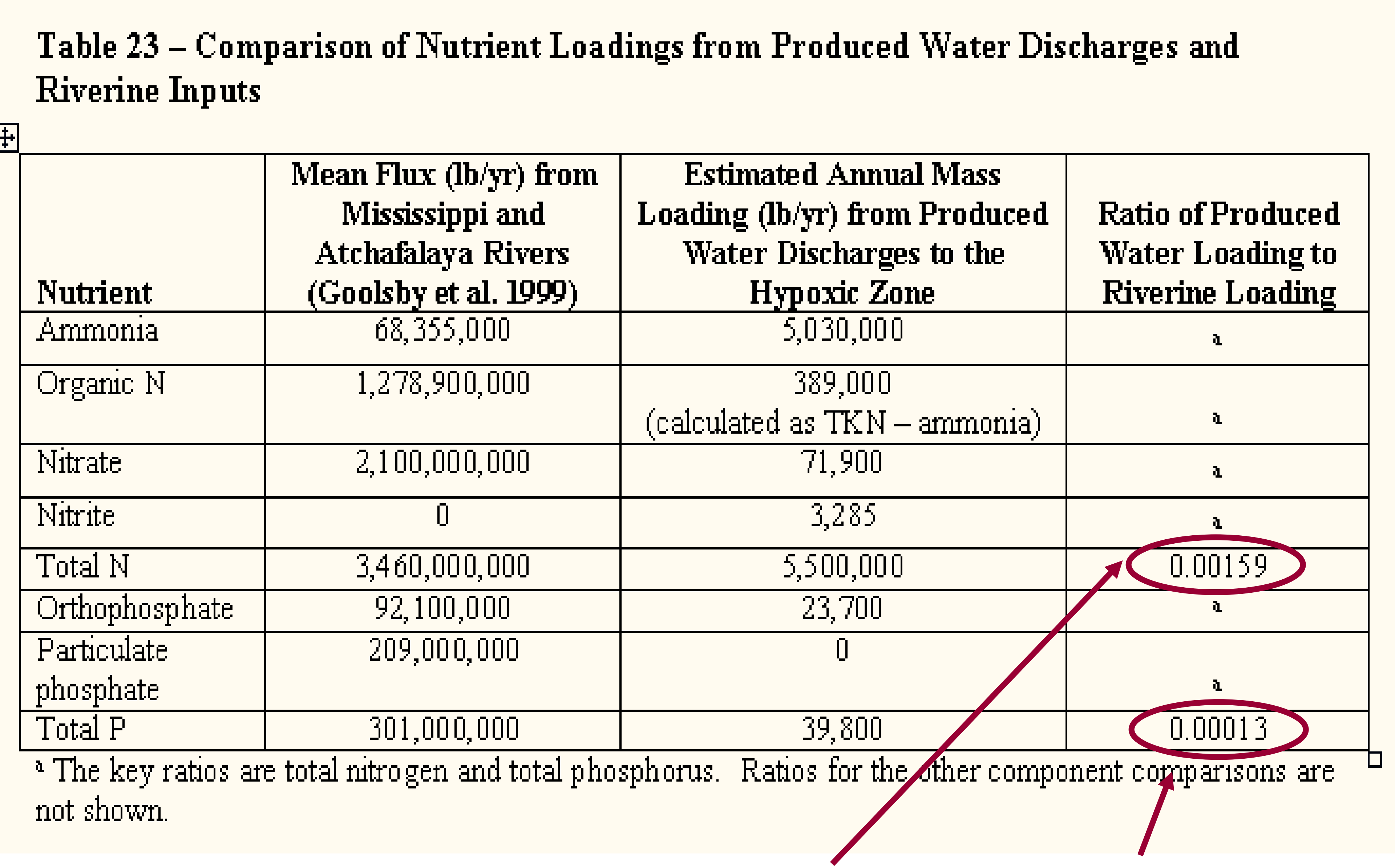


Table 23 – Comparison of Nutrient Loadings from Produced Water Discharges and Riverine Inputs

Nutrient	Mean Flux (lb/yr) from Mississippi and Atchafalaya Rivers (Goolsby et al. 1999)	Estimated Annual Mass Loading (lb/yr) from Produced Water Discharges to the Hypoxic Zone	Ratio of Produced Water Loading to Riverine Loading
Ammonia	68,355,000	5,030,000	[a]
Organic N	1,278,900,000	389,000 (calculated as TKN – ammonia)	[a]
Nitrate	2,100,000,000	71,900	[a]
Nitrite	0	3,285	[a]
Total N	3,460,000,000	5,500,000	0.00159
Orthophosphate	92,100,000	23,700	[a]
Particulate phosphate	209,000,000	0	[a]
Total P	301,000,000	39,800	0.00013

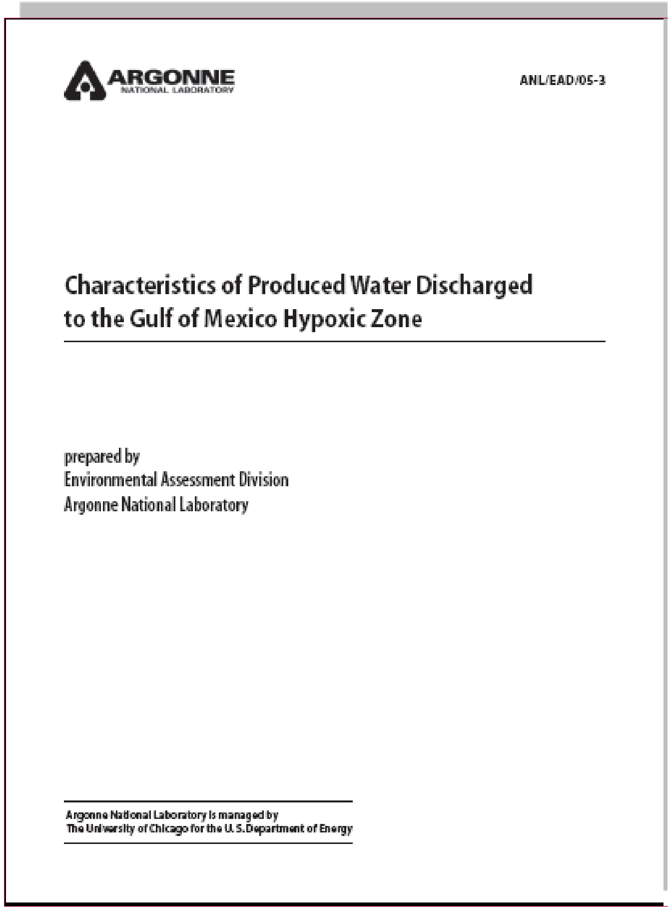
[a] The key ratios are total nitrogen and total phosphorus. Ratios for the other component comparisons are not shown.

nitrogen - 0.16%

phosphorus 0.013%

The Report Was Completed

- The hypoxic zone report was completed in August 2005 and submitted to EPA
- These data from 50 platforms represent the most complete and comprehensive effort ever undertaken to characterize the amount and potential sources of the oxygen demand in offshore oil and gas produced water discharges.
- Discharges of oxygen-demanding pollutants and nutrients are collectively large, but they represent less than 1% of the contribution of the same pollutants from the Mississippi and Atchafalaya Rivers



ARGONNE
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ANL/EAD/05-3

Characteristics of Produced Water Discharged
to the Gulf of Mexico Hypoxic Zone

prepared by
Environmental Assessment Division
Argonne National Laboratory

Argonne National Laboratory is managed by
The University of Chicago for the U.S. Department of Energy

Download report at: http://www.veilenvironmental.com/publications/pw/ANL-hypoxia-report.pdf

What Happened Next?

- EPA hired three experienced water quality modelers to run different water quality models
- Used the data from the Argonne report as inputs

EPA's Reaction

- EPA circulated a draft of the next discharge permit:

"EPA has also recently completed a study of the effects of produced water discharges on the hypoxia in the northern Gulf of Mexico and found that these discharges do not have a significant impact."

"The Region finds that discharges proposed to be authorized by the reissued general permit will not cause unreasonable degradation of the marine environment"

- The Fact Sheet accompanying the permit notes:

"EPA finds that the potential impact on the hypoxia from produced water discharges is insignificant. Therefore, no additional permit requirements are proposed at this time"

Observations and Outcome

- Government and industry worked together to design and conduct a complex sampling program
- The program was complex, but was completed in a short time frame to meet EPA needs
- The program emphasized good science and responsible QA/QC
- The sampling results were modeled by independent experts
- EPA accepted the scientific evidence and decided that the risk was low and additional regulatory controls were not needed

Conclusions

- Very large volumes of produced water are generated each year
- In collecting, treating, storing, and transporting produced water, there is some potential for environmental impacts
  - Spills and leaks
  - Discharges
  - Injection
  - Air emissions
- The size and extent of impacts is not always the same
- Impacts can be evaluated using risk assessment procedures

Conclusions (2)

- The industry can and should follow good practices for produced water management
  - Siting
  - Designing
  - Constructing
  - Operating
  - Disposing
- Although regulatory agencies tend to react strongly to potential risks, sometimes carefully conducted scientific studies can produce data to better evaluate risks and impacts