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A STUDY ON NATURAL DISASTERS AND PIPELINES (TASK 5)

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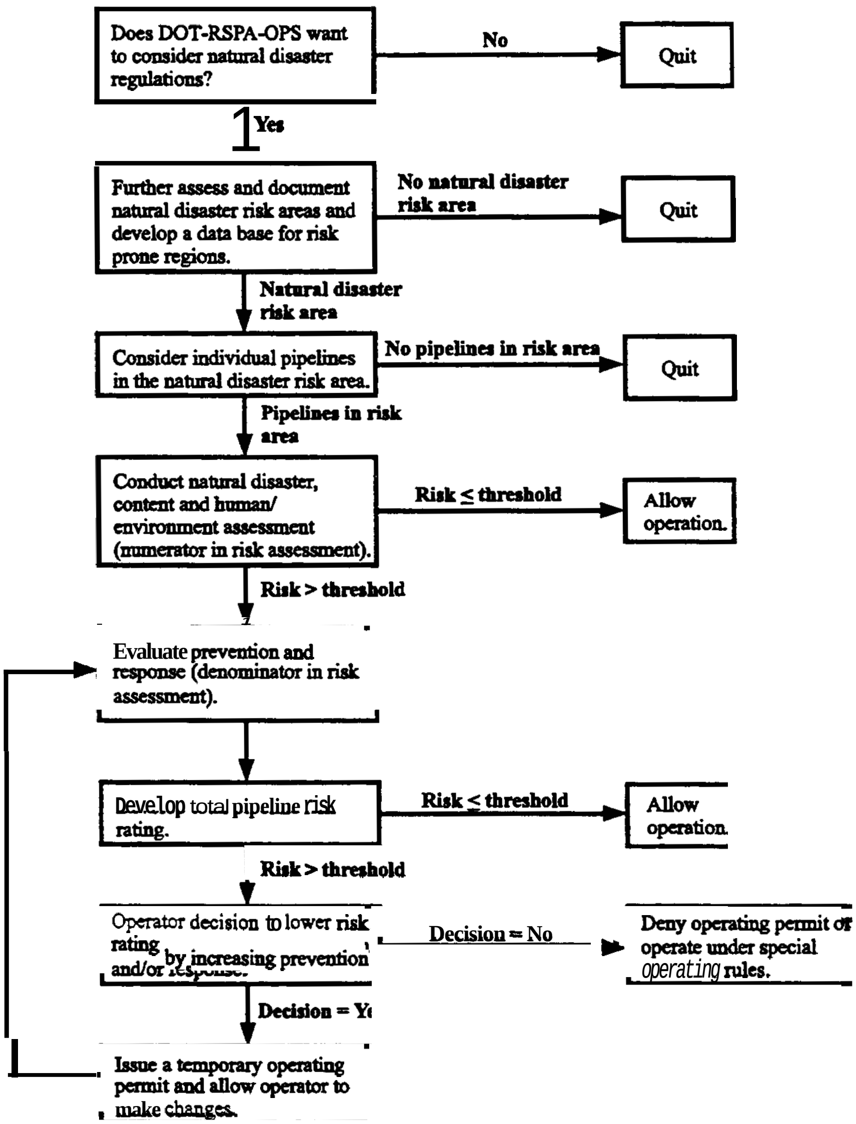
IMPLEMENTATION

Implementation of this study will be to follow up on the five focus areas identified in this report for the purpose of developing higher standards for pipelines threatened by natural disaster events. It is suggested that the initial follow-up of this study be in the form of a pilot program for developing the standards, regulations, and/or other implementation methods DOT-RSPA-OPS decides to pursue. At the end of the pilot program, implementation of this report could be further expanded as shown in the following figure.



Implementation of project study

If DOT-RSPA-OPS decides to consider a natural-disaster–based program for pipelines, a data base needs to be established for identifying natural-disaster–prone areas (i.e., the FEMA GIS data base on natural disasters). Pipelines within the natural disaster risk areas would then need to be identified. The risk assessment method described in this report could then be used to evaluate the risks associated with the pipelines identified in the natural disaster risk areas. The numerator in the risk assessment, which is a function of the natural disaster events identified in the area, pipeline content, and human- and environment-sensitive areas, would be enough information to prove a pipeline to be within an acceptable risk range (i.e., overall risk $\leq$ threshold limit) but not enough to justify special operating requirements or denial of an operating permit for a pipeline. Therefore, if the pipeline's risk rating was above the acceptable risk range at this point, an evaluation of prevention and response would need to be conducted. The total pipeline risk rating could then be determined as the final analysis for the system. If the risk was at or below the acceptable risk range, the pipeline could proceed with its normal operations. If the overall rating was above the acceptable risk range, the pipeline operator could decide whether or not it wanted to lower the risk by making prevention and/or response changes. If the pipeline company decided to try and lower the risk, it could be issued a temporary operating permit until it made its changes. At the end of the temporary permit time, the pipeline's prevention and response could be reevaluated and continue through the same process. If the pipeline company decided not to try and lower its risk rating, the pipeline could operate under special operating requirements or be denied an operating permit, as decided by DOT-RSPA-OPS.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation, nor is it intended for construction, bidding, or permit purposes. The engineer in charge of the project was Dr. Roy W. Hann, Jr., P.E. # 24233 TX.

SUMMARY

Past pipeline failure reports have typically focused on corrosion and third-party–related events. However, natural disasters pose a risk to pipeline integrity as well. Therefore, it was the objective of this report to analyze the risks and consequences of pipelines being seriously affected by natural disasters and propose potential measures to prevent leaks or spills, and to mitigate the consequences of leaks and spills resulting fiom natural disasters.

This report has reviewed various pipeline types, natural disasters and modes of impact, and failure modes that affect the stability of pipeline systems. A risk assessment method has been discussed and displayed in a workable format that takes into account natural disasters, pipeline contents, human and environmental receptors, and prevention and response concepts that can help prevent and mitigate pipeline failures resulting fiom natural disasters.

Five areas have been identified that researchers believe contain significant pipeline systems that are threatened by natural disasters. The identification of these highly threatened pipeline areas coincides with the findings of the Federal Emergency Management Agency's report on natural-disaster–prone areas. These areas are:

1. San Jacinto/Houston Ship Channel area in Texas,
2. southern Louisiana coastal area,
3. Venture County in California,
4. Cushing, Oklahoma, area, and
5. San Francisco Bay area in California.

The risk assessment process described in this report provides pipeline operators with a way of lowering the risks associated with pipelines threatened by natural disasters by increasing prevention and/or response methods. Prevention and response methods have been thoroughly discussed throughout this report, and several recommendations have been made that would help in increasing a pipeline's prevention and response actions. These recommendations include:

- OPS shall consider the implementation of this risk assessment system or one including its basic concepts.
- It is appropriate to consider new pipelines and existing pipelines as separate issues in implementing the system.
- Pipeline companies should have a risk-based management program which includes natural disaster risks and which is strongly based on prevention.
- OPS should promulgate a set of higher standards or guidelines, which can be used to evaluate prevention levels above the minimum requirements in natural-disaster–prone areas. These standards could include activities in design, construction, maintenance, operations, training, supervision, and enforcement.
- Pipelines should have overall corporate or regional contingency plans as well as individual pipeline (segment, branch, or subsidiary) facility response plans for oil and other product releases.
- DOT-RSP oil spill response plan regulations for pipelines should have measurable time tiered response planning standards for response resources (e.g., Skimmers, recovered product storage, and booms) as Federal regulations require for storage facilities, vessels, and marine transfer facilities.
- OPS should develop a rating system for response plans which will provide for other than a simple approval/disapproval system and which can be used in this risk analysis system.
- Contingency and response glans should be rated higher if formatted based on the NIMS incident command system as currently being used by the USCG and EPA in area Contingency plans. This will help pipeline operators to better interact with Federal response agencies during drills and spill events.

We have deliberately not been specific with regard to how the Office of Pipeline Safety should use regulations or other means to implement enhanced requirements for pipelines in hazard-prone areas.

Historically, enhanced programs for human and environmental protection have focused on existing facilities separate fiom new facilities. This would also be appropriate for pipelines. Higher level requirements are required for new pipeline facilities in hazard-prone areas and an improved but less stringent requirement established for existing pipelines—usually with years of grace period to come into compliance.

By using the risk assessment process approach of this project, the regulated pipeline would be able to select which mix of prevention and response preparedness enhancements they would choose to lower their modified risk level to acceptable levels. This concept is in conformance with the Common Sense Initiative in the Federal Pollution Prevention Act and in risk-based environmental management programs.

This project has fulfilled its stated objectives by the following:

- The problem of natural disasters and their effect on pipelines have been examined, and with a companion FEMA project, several high risk areas have been determined.
- A method to establish a risk rating based on measurable parameters has been developed.
- A method to lower the risk rating based on prevention and response preparedness has been developed.
- Suggestions for implementing this program using the risk assessment process have been presented which emphasize pipeline industry choice in selecting ways of reducing the risk rating in natural-disaster-prone areas.

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CHAPTER I
INTRODUCTION

Researchers have studied the potential of pipeline failures in various ways. Typically these studies focus on corrosion and third-party-related incidents. Although these types of events may account for the majority of pipeline failures, potential catastrophic damage to pipelines due to natural disaster events needs to be analyzed so measures can be developed to help prevent or mitigate future pipeline failures.

This report details findings fiom a study of pipeline hazards related to natural disasters. Combined with corrosion and third-party event studies, it broadens the overall pipeline failure picture (see figure 1).

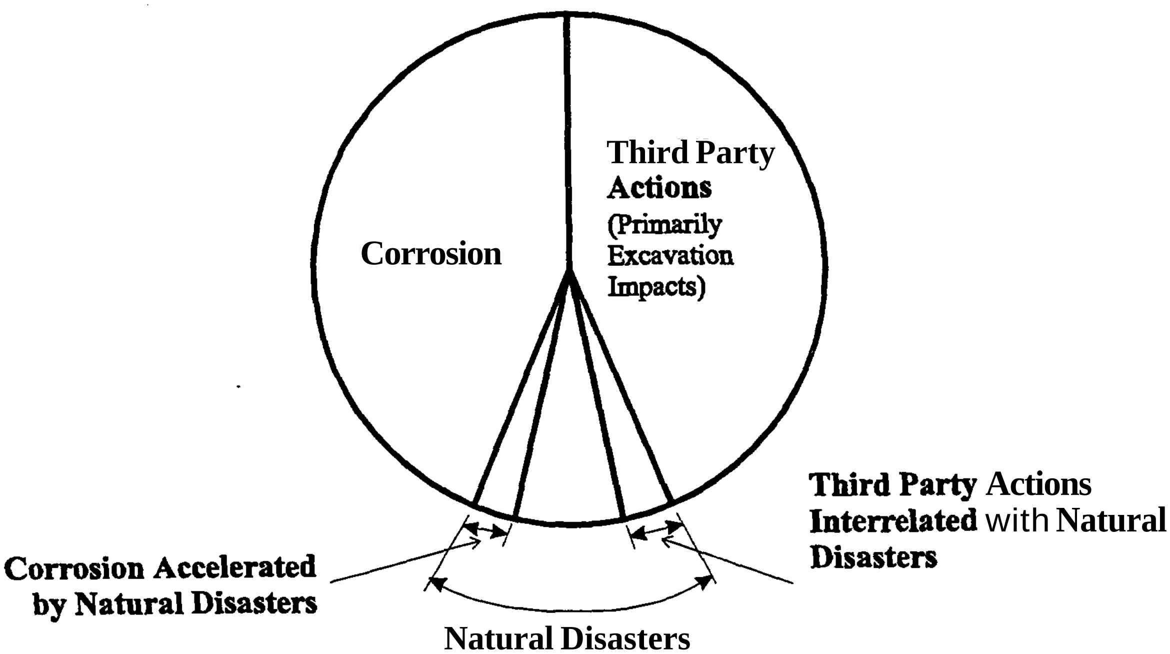


Figure 1: Events leading to pipeline failure

This diagram shows that the majority of pipeline failures result from corrosion and third-party actions and that there are fewer failures that are entirely linked to natural disasters. It also shows that there are other failures where natural disasters contribute to corrosion and third-party action failures.

The second chapter in this report looks at the types of natural disaster events to which pipelines are exposed; the various types of pipelines in terms of their unique properties, use, and materials transported; and the different modes of impact and failure modes that pipelines experience fiom the natural disaster events. Several pipeline types, although impacted by natural disasters, are too rare to warrant specific study and reporting at this time.

The third chapter focuses on the location, magnitude, and frequency of natural disaster events; acute and chronic hazards associated with various pipeline contents; and susceptibility for harm to humans, economic, and environmental systems. It also includes a look at prevention measures'and emergency responses to pipeline failures undertaken in reducing the risks.

Chapter IV describes three major steps to eliminate the risk or minimize the impact of pipeline failure. The initial part of this chapter explores how design, construction, maintenance, operations, training, supervision, and enforcement may be integrated into a comprehensive prevention program to reduce the risks.

The second part of chapter IV deals with acceptance of individual risks and the need to plan for effective response to undesirable events. This section outlines current concepts regarding spill/release response management concepts including those based on the Incident Command System.

The third part of chapter IV addresses the concepts of release response readiness. It shows how a foundation of corporate, contractor, and public response resources, coupled with training, inspections, and drills, can maintain a state of readiness which will lead to effective response with associated reductions in human injury, economic cost, and environmental damage.

Chapter V of this report considers several areas of the country identified by the project and the Federal Emergency Management Agency (FEMA) contractor as high risk areas. Their locations and susceptibilities will be displayed and discussed.

Chapter VI summarizes report findings and presents specific recommendations.

CHAPTER II

REVIEW OF NATURAL DISASTERS, TYPES OF PIPELINES, POTENTIAL OR OBSERVED MODES OF IMPACT ON PIPELINES, AND FAILURE MODES

To conduct an analysis on pipeline failure resulting from natural disaster events, it is important to understand the impact and failure modes of pipelines associated with natural events. For the purpose of this study, pipeline failure is defined as any release of pipeline contents which poses a substantial present or potential hazard to health or the environment due to quantity, concentration, or physical or chemical characteristics.

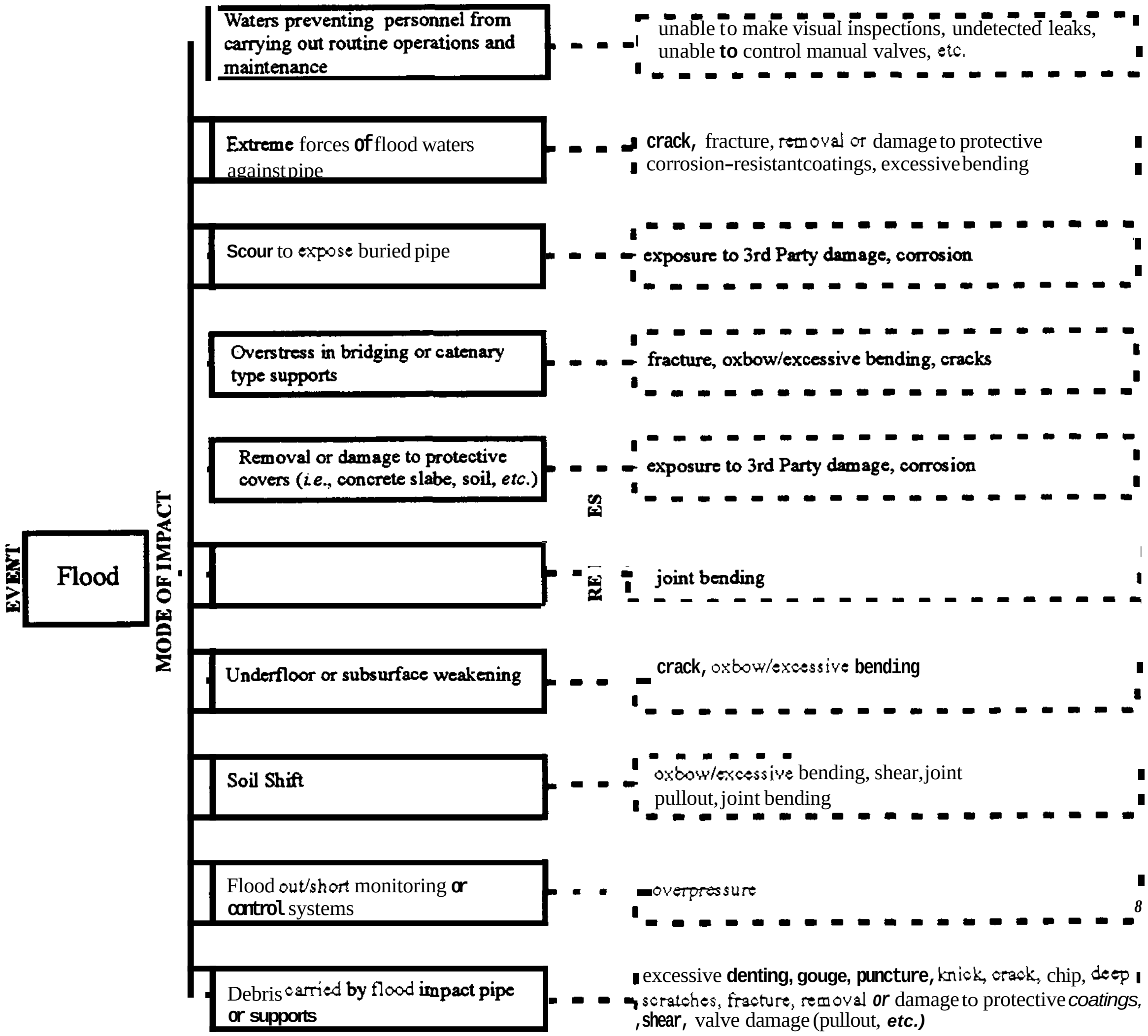
Failure modes are any causes that lower or damage the integrity of a pipeline system. Modes of impact are the actions of natural disaster events that lead to failure modes.

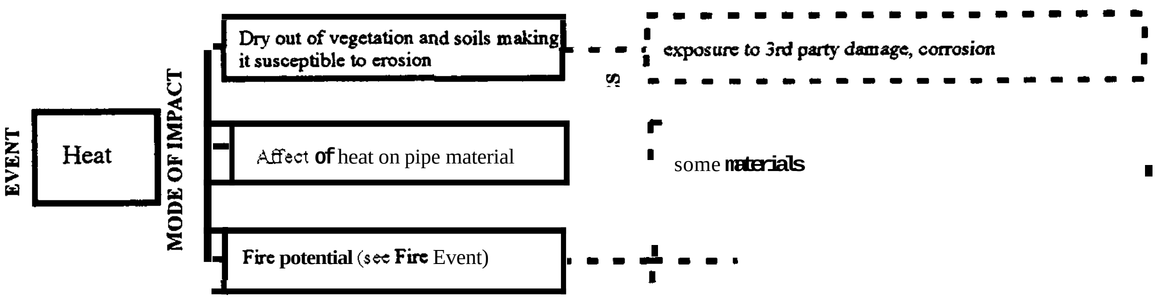
A tree diagram, such as those in figures 2 through 17, can be quite useful for assessing the question of ***"What modes of impact andfailure modes are associated with each natural disaster event?"*** To use this type of diagram, first determine the modes of impact for each type of natural disaster event. Next determine failure modes typically associated with each type of mode of impact. Failure modes may be extensive for many events; however, the main focus here is to identify the modes of impact. By identifying impacting forces, it becomes possible to plan for prevention, reducing or eliminating failure modes associated with natural disaster events.

The modes of impact and failure modes for selected natural disaster events are shown in figures 2 through 17. Note that in some cases, the natural disaster event may lead to a mode of impact that is considered another natural disaster. In this case, the mode of impact would branch off into another natural disaster event. The events not shown in these figures are either not considered natural disasters or there is insufficient data and/or knowledge on the event.

Researchers evaluated events for this study on conditions that produce the event and separated them into four categories, The categories are:

1. weather-related events,
2. man-related events,
3. Geology-related events, and
4. other events.


EVENT
Flood
MODE OF IMPACT
Waters preventing personnel from carrying out routine operations and maintenance
unable to make visual inspections, undetected leaks, unable to control manual valves, etc.
Extreme forces of flood waters against pipe
crack, fracture, removal or damage to protective corrosion-resistant coatings, excessive bending
Scour to expose buried pipe
exposure to 3rd Party damage, corrosion
Overstress in bridging or catenary type supports
fracture, oxbow/excessive bending, cracks
Removal or damage to protective covers (i.e., concrete slabe, soil, etc.)
exposure to 3rd Party damage, corrosion
ES
RE
joint bending
Underfloor or subsurface weakening
crack, oxbow/excessive bending
Soil Shift
oxbow/excessive bending, shear, joint pullout, joint bending
Flood out/short monitoring or control systems
overpressure
Debris carried by flood impact pipe or supports
excessive denting, gouge, puncture, knick, crack, chip, deep scratches, fracture, removal or damage to protective coatings, shear, valve damage (pullout, etc.)


EVENT
Heat
MODE OF IMPACT
Dry out of vegetation and soils making it susceptible to erosion
exposure to 3rd party damage, corrosion
Affect of heat on pipe material
some materials
Fire potential (see Fire Event)

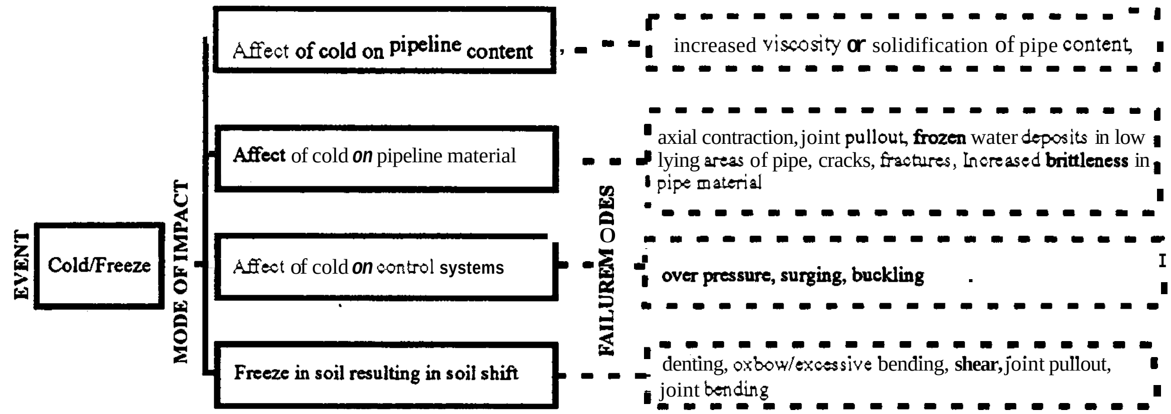


Figure 4: Tree diagram for cold/freeze event

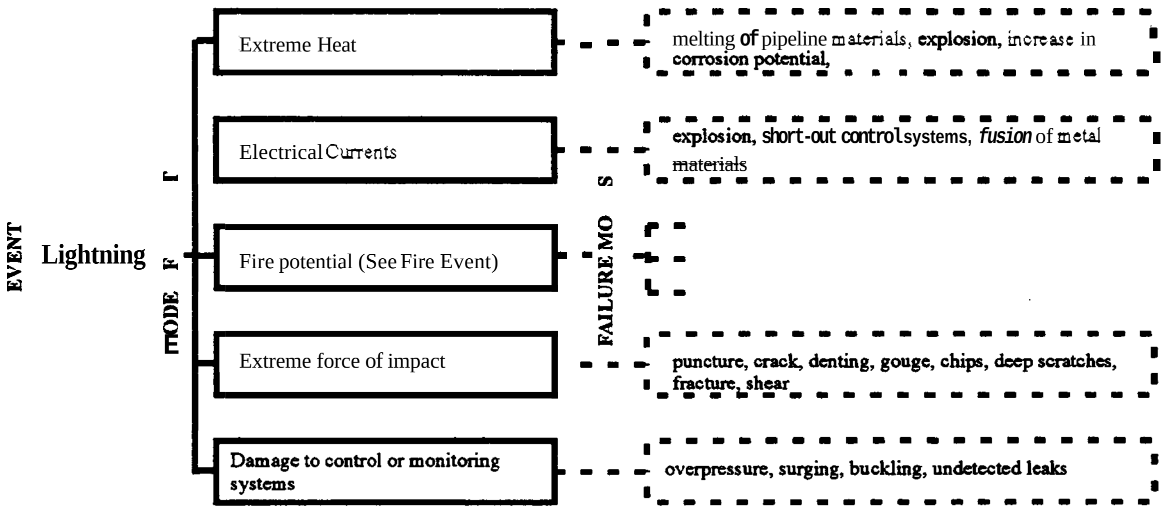
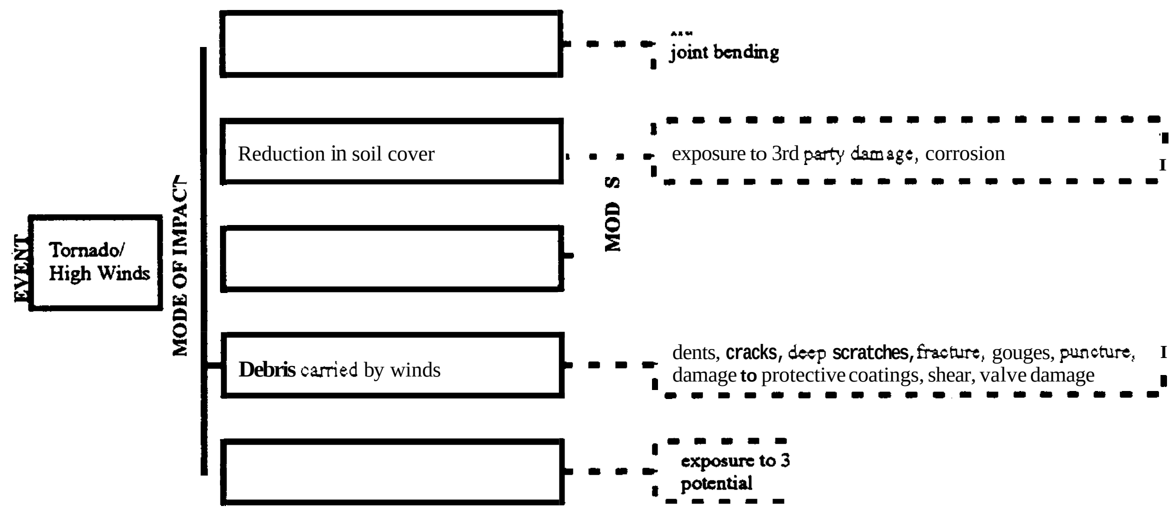


Figure 5: Tree diagram for lightning event



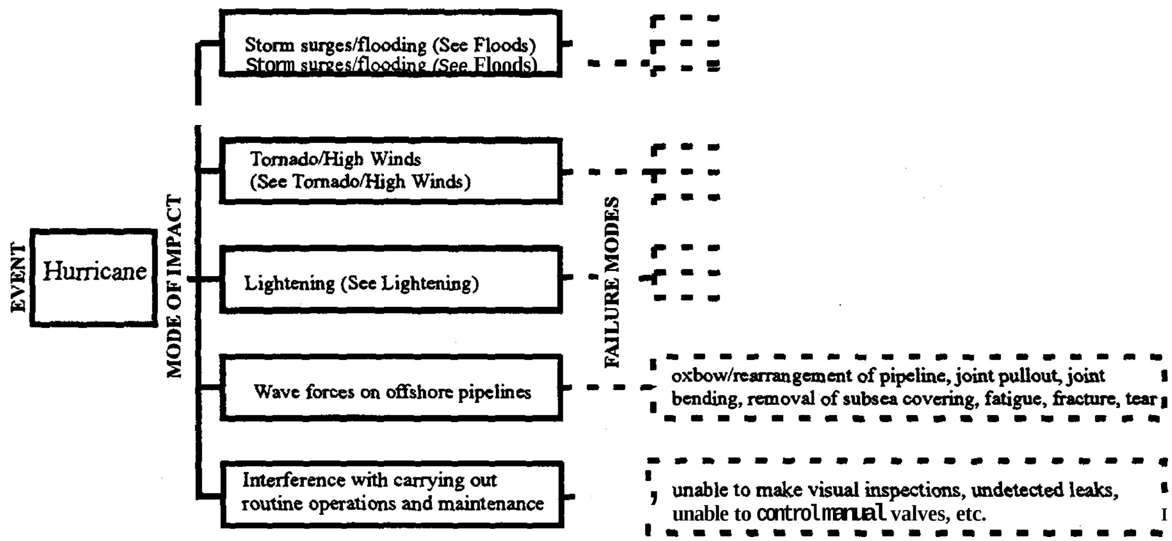


Figure 7: Tree diagram for hurricane event

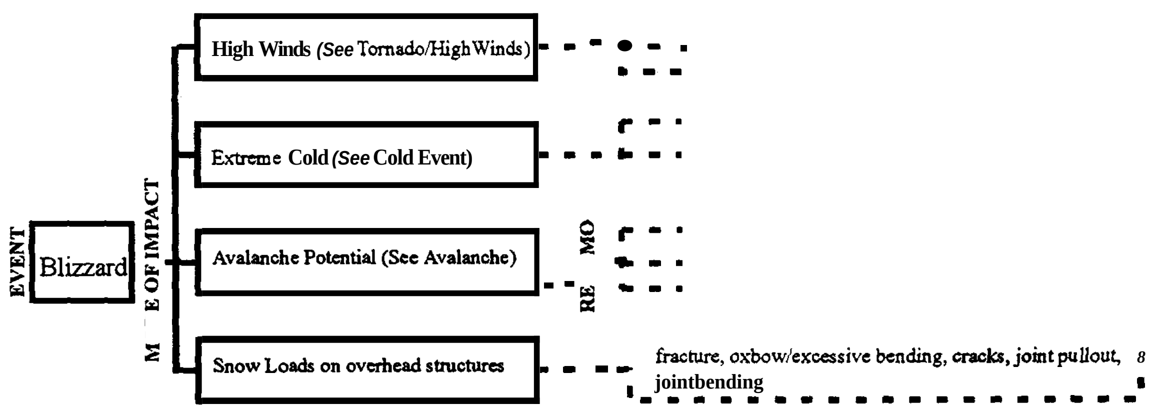


Figure 8: Tree diagram for blizzard event

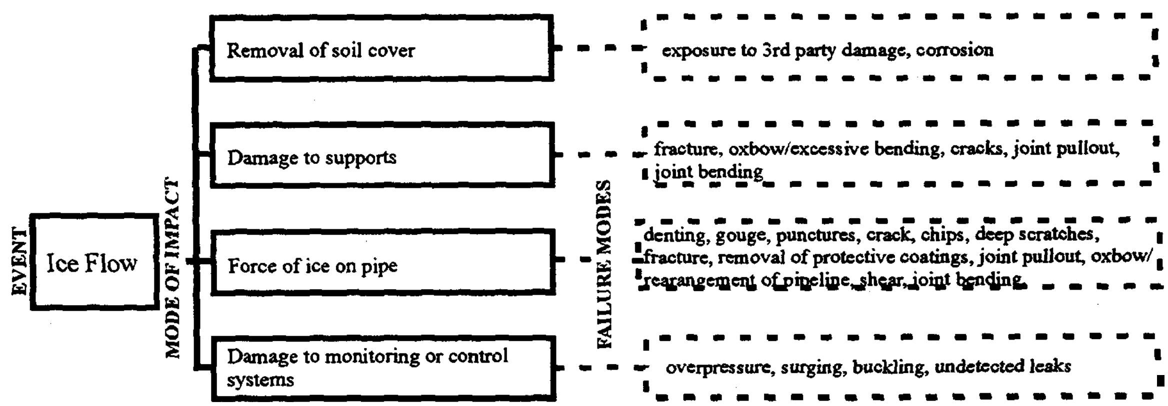


Figure 9: Tree diagram for ice floe event

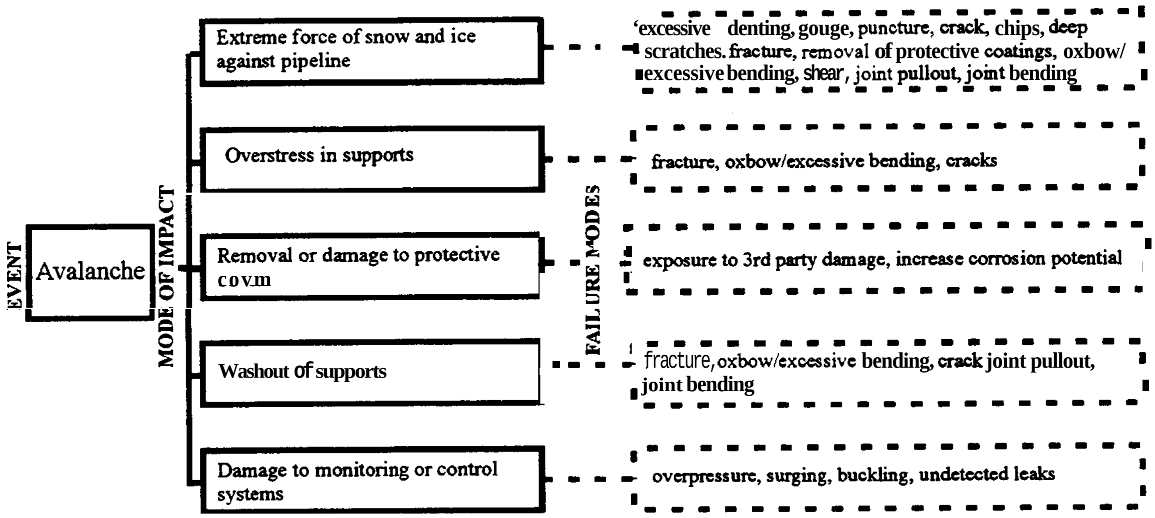


Figure 10: Tree diagram for avalanche event

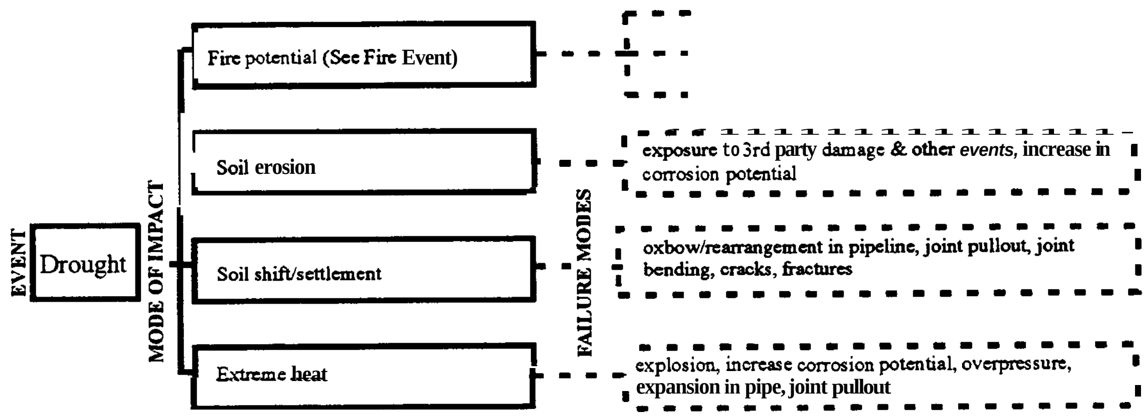


Figure 11: Tree diagram **for** drought event

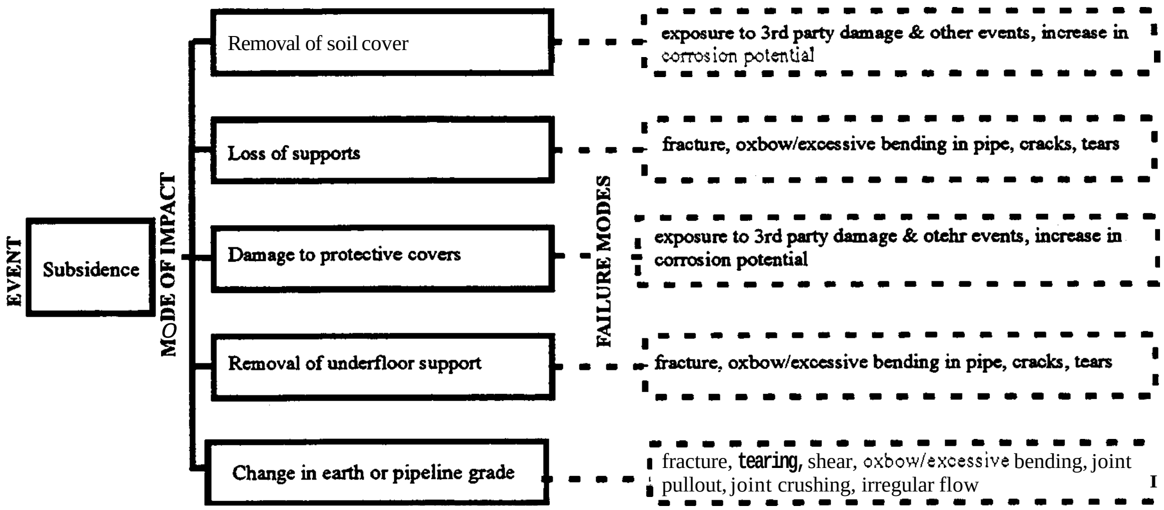


Figure 12: Tree diagram for subsidence event

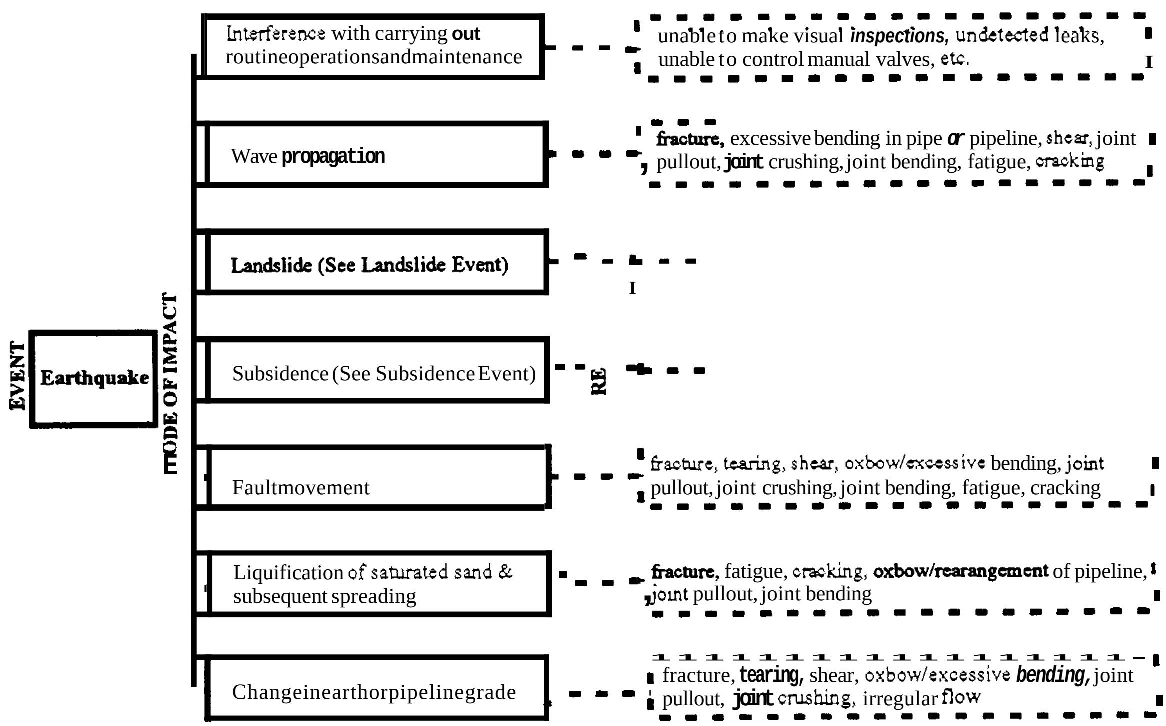


Figure 13: Tree diagram for earthquake event

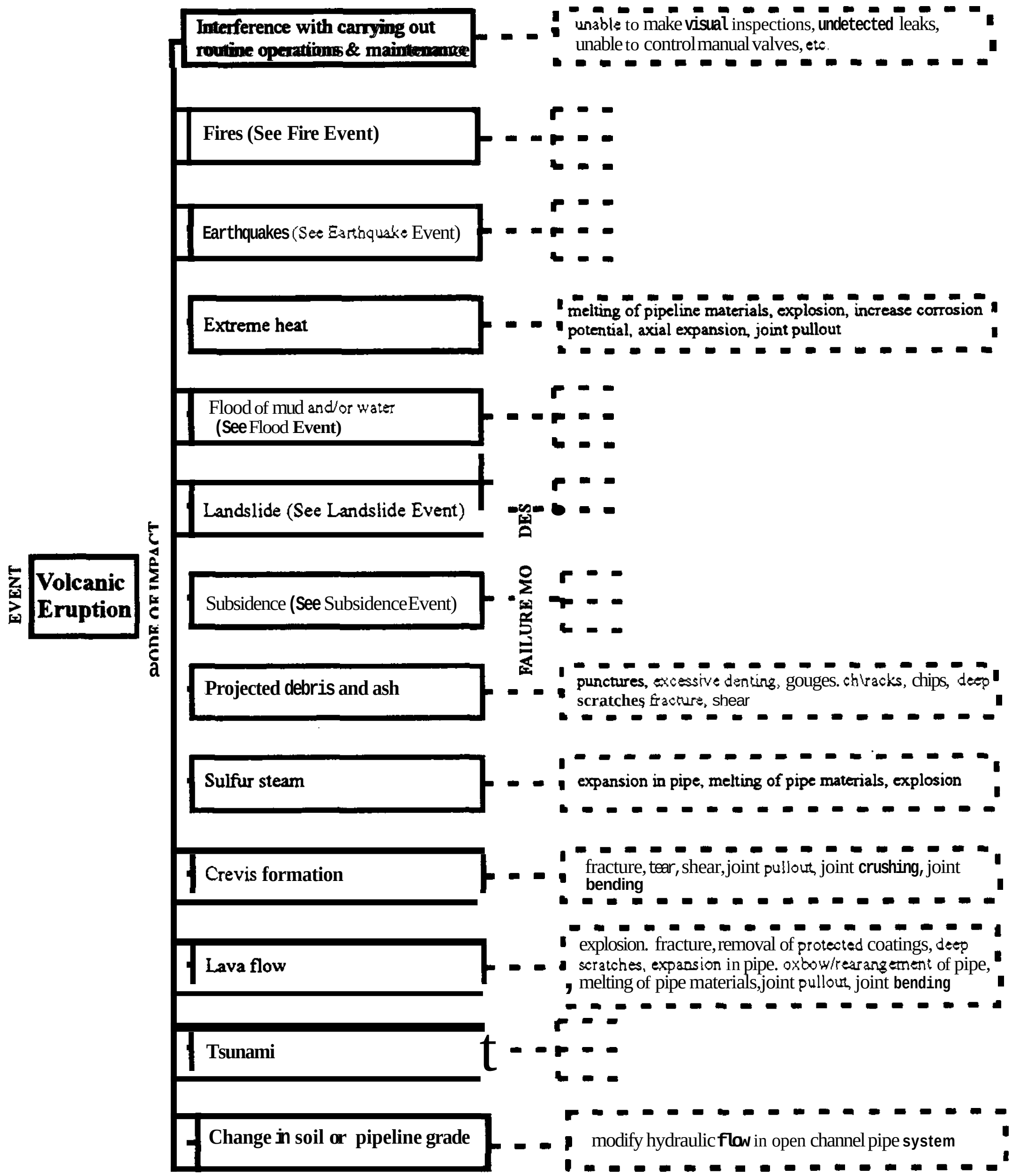


Figure 14: Tree diagram for volcanic eruption event

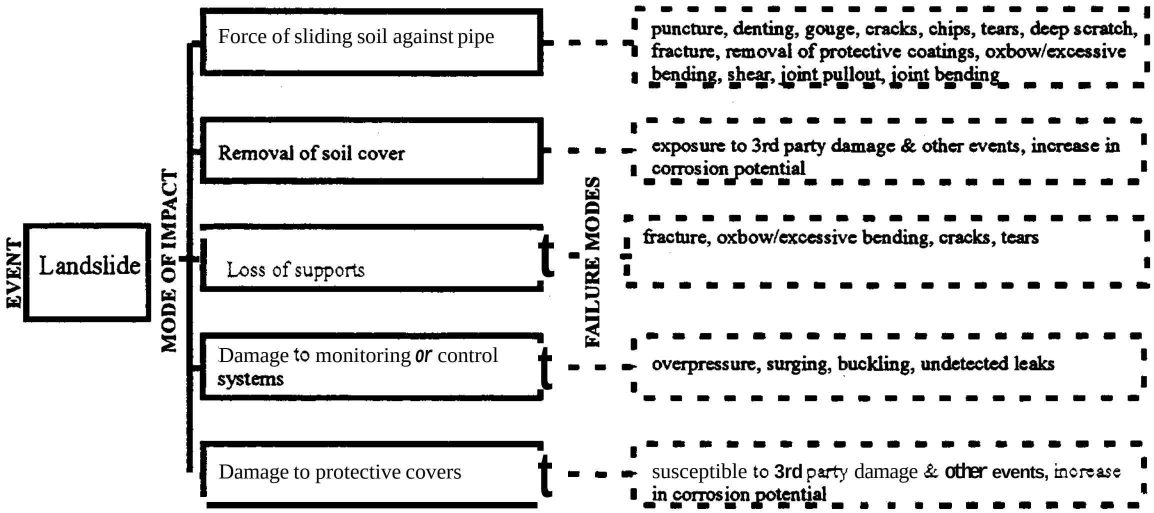


Figure 15: Tree diagram for landslide event

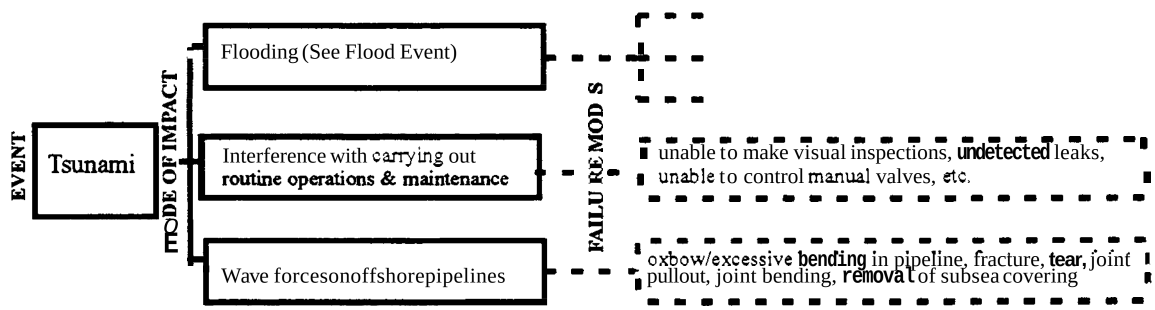


Figure 16: Tree diagram for tsunami event

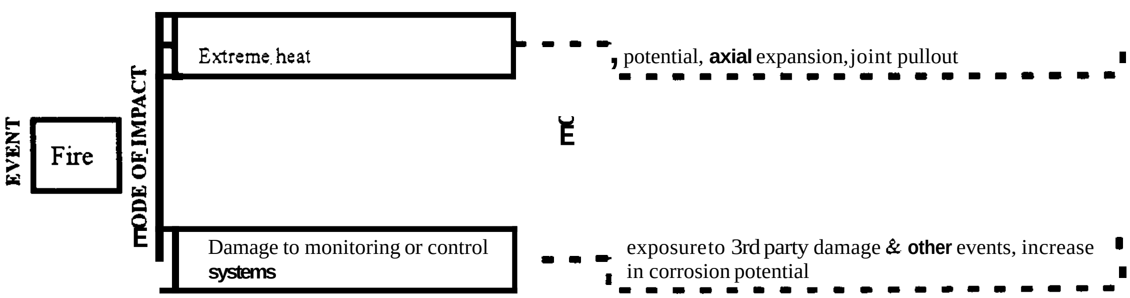


Figure 17: Tree diagram for fire event

Table 1 lists each of the individual events separated into their appropriate categories.

Table 1: Categorized events

WEATHER RELATED	GEOLOGY RELATED
• Heat	• Volcanic Eruptions
• Cold	• Earthquake
• Flood	• Subsidence
• Lightning	• Landslide
• Tornado/High Winds	• Tsunami
• Hurricane	• Quick Clay
• Blizzard	• Quicksand
• Ice Flows	
• Avalanche	
• Drought	
• Permafrost	
MAN RELATED	**OTHER EVENTS**
• 3rd Party	• Corrosion
• Operations	• Fire (forest & other)
• Construction Flaws	
• Electrical Sparks	

Events considered for this study are ones that have a history of frequent occurrence. They were evaluated for specific geological locations and for unique properties that contribute to pipeline failure. Please note that although volcanic eruptions and tsunamis have not historically contributed to pipeline failures, they pose considerable risks that warrant consideration. The resulting natural disaster events are fires and those that fall under the weather- and geology-related event categories.

The following list shows the types of pipelines considered and included in this study.

1. Crude oil
   - Main pipelines
   - Gatheringlines
2. Emulsions
3. Naturalgas
4. Liquefied petroleum gas
5. Refined petroleum product
6. Storage tanks associated with pipelines

The following list includes those pipelines considered in the general evaluation of this project; however, they were excluded because they do not come into the purview of DOT-RSPA-OPS.

1. Chemicals
2. Toxic/hazardous materials/waste
3. Other gases
4. Salt brine
5. Fresh water
6. Sewers
7. Slurry

Crude Oil Pipelines

Crude oil is extracted at widely scattered locations, and the resulting crude is trucked or piped to receiving centers where it is then pumped through larger pipelines to refineries. Collecting or gathering lines generally are more temporary, operate at lower pressures, are smaller in diameter, and have lower flow volumes. The larger or main crude oil pipelines carry collected oil or imported oil fiom terminals to refineries for processing. These pipelines vary in diameter and flow volume. When they fail, the spill volumes are often large and the resulting oil spill has the potential for fires, economic impact, and ecological impact.

Emulsions Pipelines

Some crude oils are too thick to be effectively transported by pipelines (even heated ones). Recent developments make it possible for these crudes, or partially refined residual fuel oils, to be transported and burned for fuel as water in oil or oil in water emulsions (ORE-Emulsions).

A pipeline release of emulsion would result in an oil spill with different characteristics than a crude oil spill. For example, the emulsion could form a mousse that is denser than water and settle into the water column making it difficult to clean up.

Natural Gas

Natural gas, like crude oil, is produced in scattered locations. The gas is collected through a gas gathering system. Collected gas is then transported to a gas plant for processing and then to a major population center or to a major gas-consuming industry through major natural gas pipelines. The main pipelines are generally larger in diameter than gathering lines and carry higher volumes of gas at higher pressures. Compressor stations re-pressure the gas along the pipeline, and large natural gas storage facilities exist, both above and below the ground surface, to store the gas at both the collection and receiving location. In large urban areas, natural gas is distributed to businesses, homes, and factories through a distribution network of smaller and smaller pipes and at lower and lower pressures.

Natural gas pipeline ruptures may release large volumes of gas in the form of a vapor cloud, subject to ignition from flame sources. Even relatively small ruptures in the distribution system can hold explosion potential.

Natural gas systems (gathering, transmission, distribution, and storage) are among the most susceptible to a wide range of natural disaster events.

Liquified Petroleum Gas Pipelines

Butane and propane are often produced with natural gas and are separated, transported, and sold as liquified petroleum gas (LPG). These materials, which are gaseous at standard temperature and pressure, are easily compressed and maintained in a liquid form.

LPG is widely used as engine fuel and as a heating source in areas not served with natural gas. Main LPG pipelines carry LPG fiom processing centers to storage centers and from storage centers to distribution centers. Primary distribution to the public is by rail cars or pressurized tanker trucks.

LPG releases can be even more dangerous than natural gas releases because LPG gases are heavier than air and their vapor clouds tend to collect near the ground and in low-lying areas. An ignition source can then set off the vapor cloud and explode.

Refined Petroleum Product

Often the public prefers that oil refining take place where the oil is produced rather than near the consuming urban centers. Pipelines then serve to move a wide range of products including gasoline, diesel fuel, aviation fuel, home heating oil, and heavy industrial fuel fiom the refinery center or importing center to distributing centers for further distributed via barge, truck, andor rail. This distribution system is also vulnerable to natural disaster disruption with risks from explosion and fire dangers of the lighter fuels to the toxic and smothering nature of some of the heavier products.

Storage Tanks

Storage tanks are included in this study because they are often part of integrated pipeline systems. Certain regulations, notably Under Ground Storage Tank regulations, include the volume of underground piping and pumping systems in determining if a tank system qualifies as an under ground storage tank subject to regulation.

For the most part, this project will focus on crude oil, natural gas, LPG, and refined petroleum product pipelines. This is because these type of pipelines fall within main domain of the Office of Pipeline Safety (OPS) and because there are better maps available for these than other types of pipelines (i.e., sewer, slurry, etc.). However, the reader should recognize that the topic and technology apply equally well to other forms of pipelines.

CHAPTER III
RISK ASSESSMENT

The risk assessment method described in this report is presented in a workable format that can be applied to any pipeline system. The method deviates from calculation-intense probabilistic theory and concentrates on historical data, experience, and common knowledge. Where possible, it defines and quantifies risks associated with pipeline failures. This process is as much an art as a science; therefore, value judgments have been used for some risk aspects. This allows many risk parameters to be accounted for that would otherwise be left out because of their difficulty to quantify and define.

The main categories for the baseline risk assessment are shown in figures 18 through 24 and are discussed in the subsections of natural disaster assessment, content assessment, human and environmental systems assessment, prevention and release response assessment, and risk characterization.

Natural Disaster Assessment

In evaluating the risk of natural disaster events occurring in specified locations, review and analyze all relevant, current, and past data. A good starting point for determining if a natural disaster event should be considered in the analysis is evaluation of the area's geographical location. For a specific geographical location, improbable events for that area can be eliminated and ostensible events can be added and further studied. For example, a pipeline located at an inland area such as Cushing, Oklahoma, is unlikely to be threatened by a hurricane, whereas a pipeline located at a coastal area such as southern Louisiana is highly likely to be affected by a hurricane.

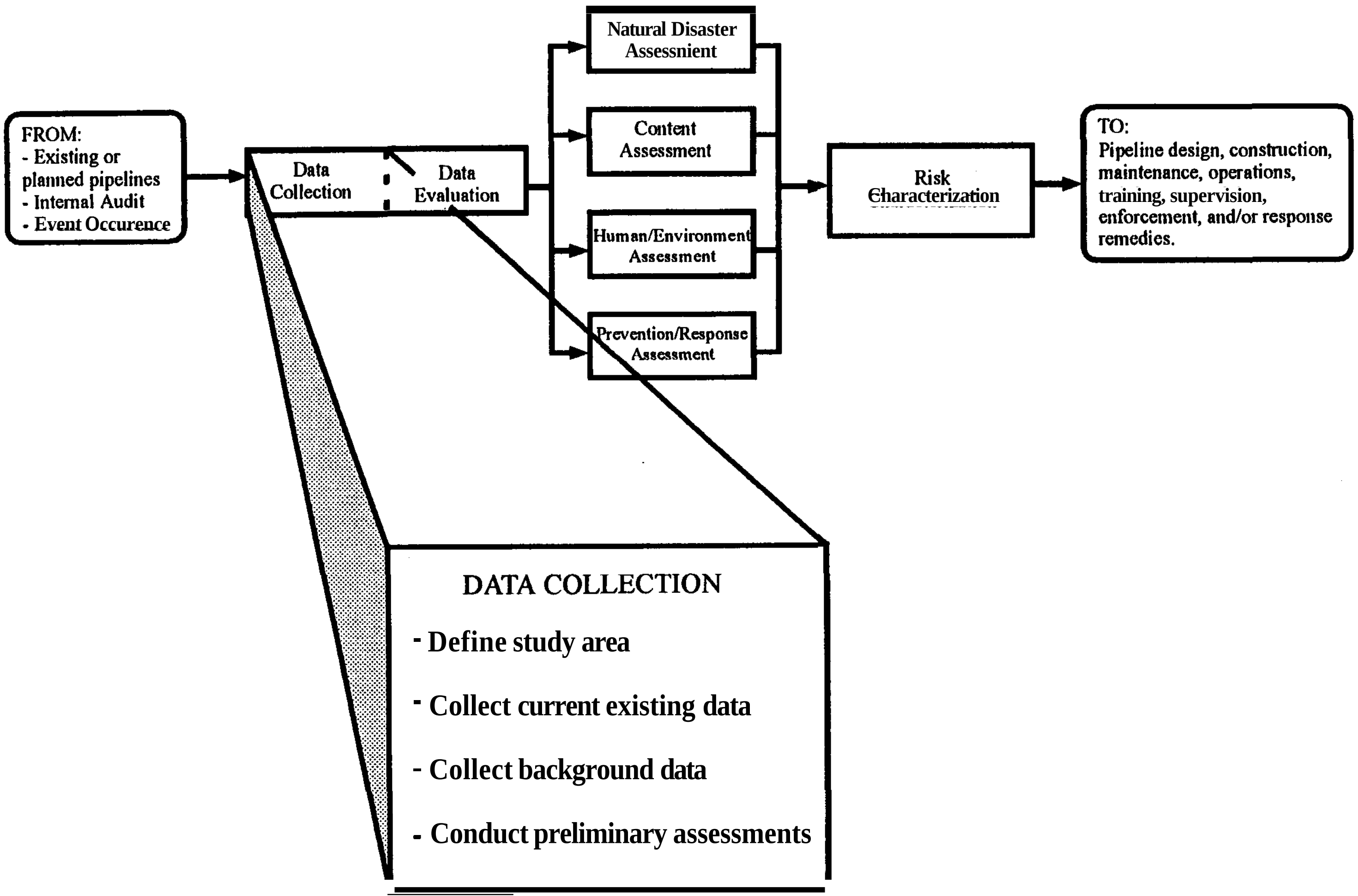


Figure 18: Data collection

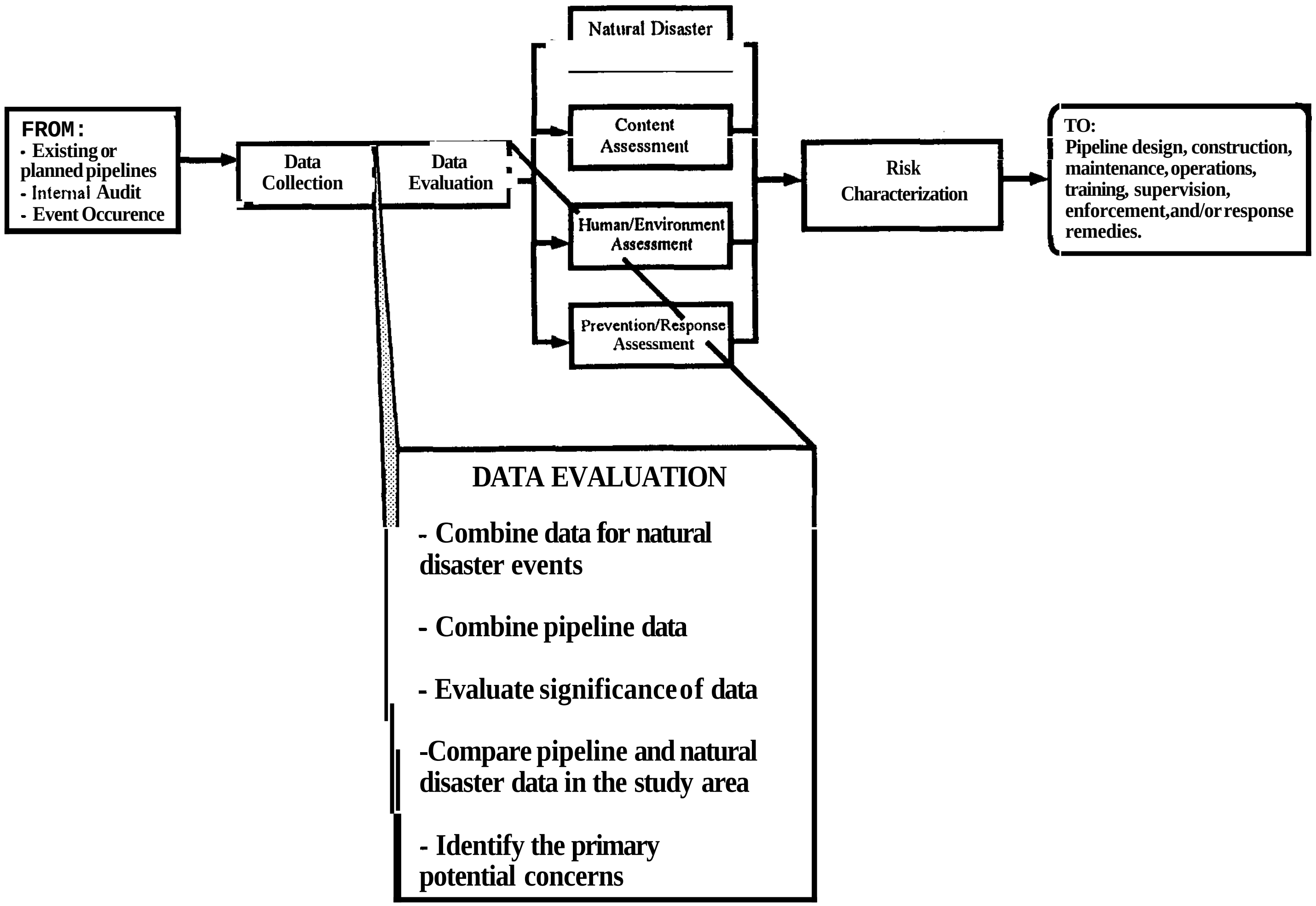


Figure 19: Data **evaluation**

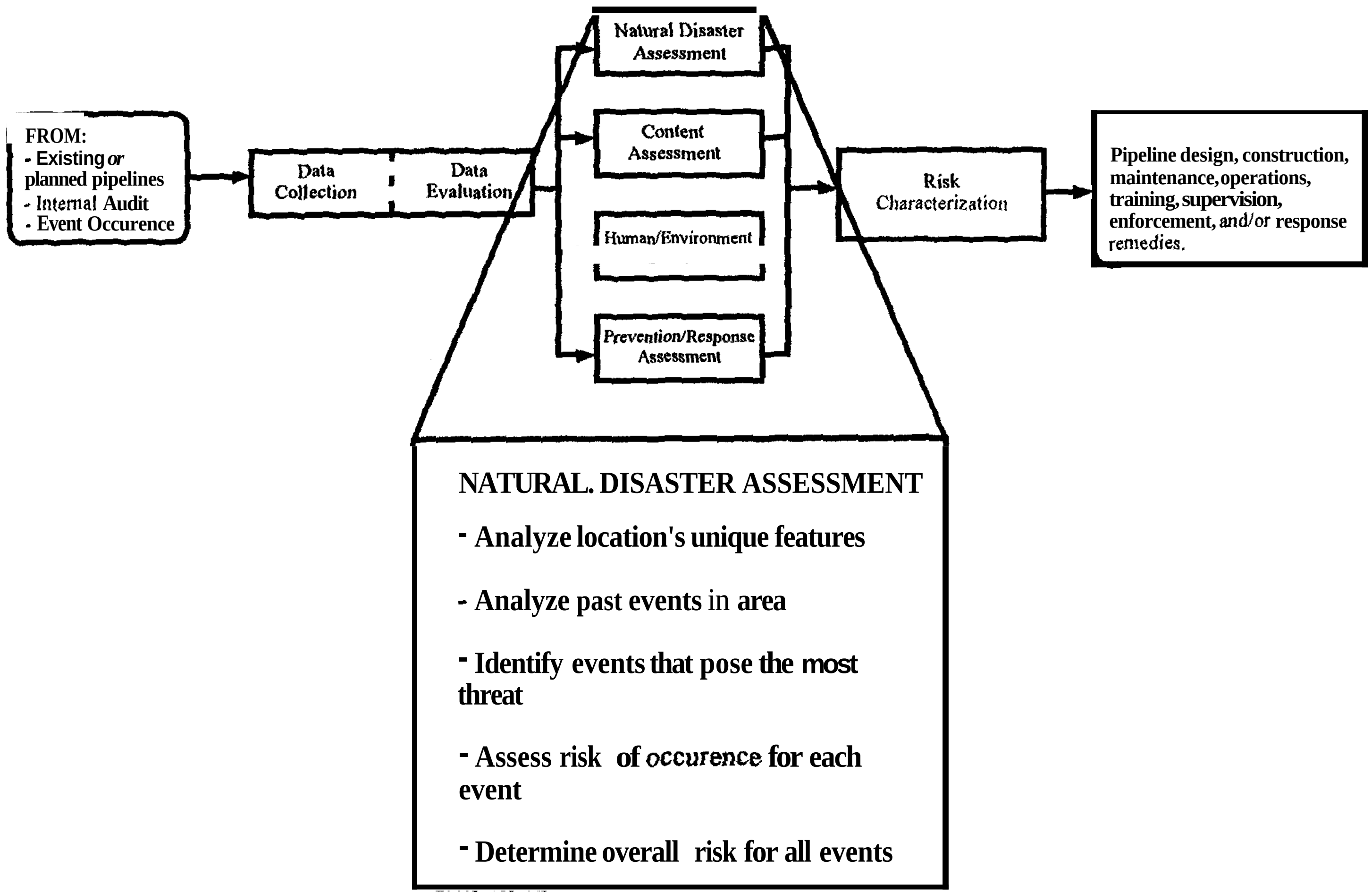


Figure 20: Natural disaster assessment

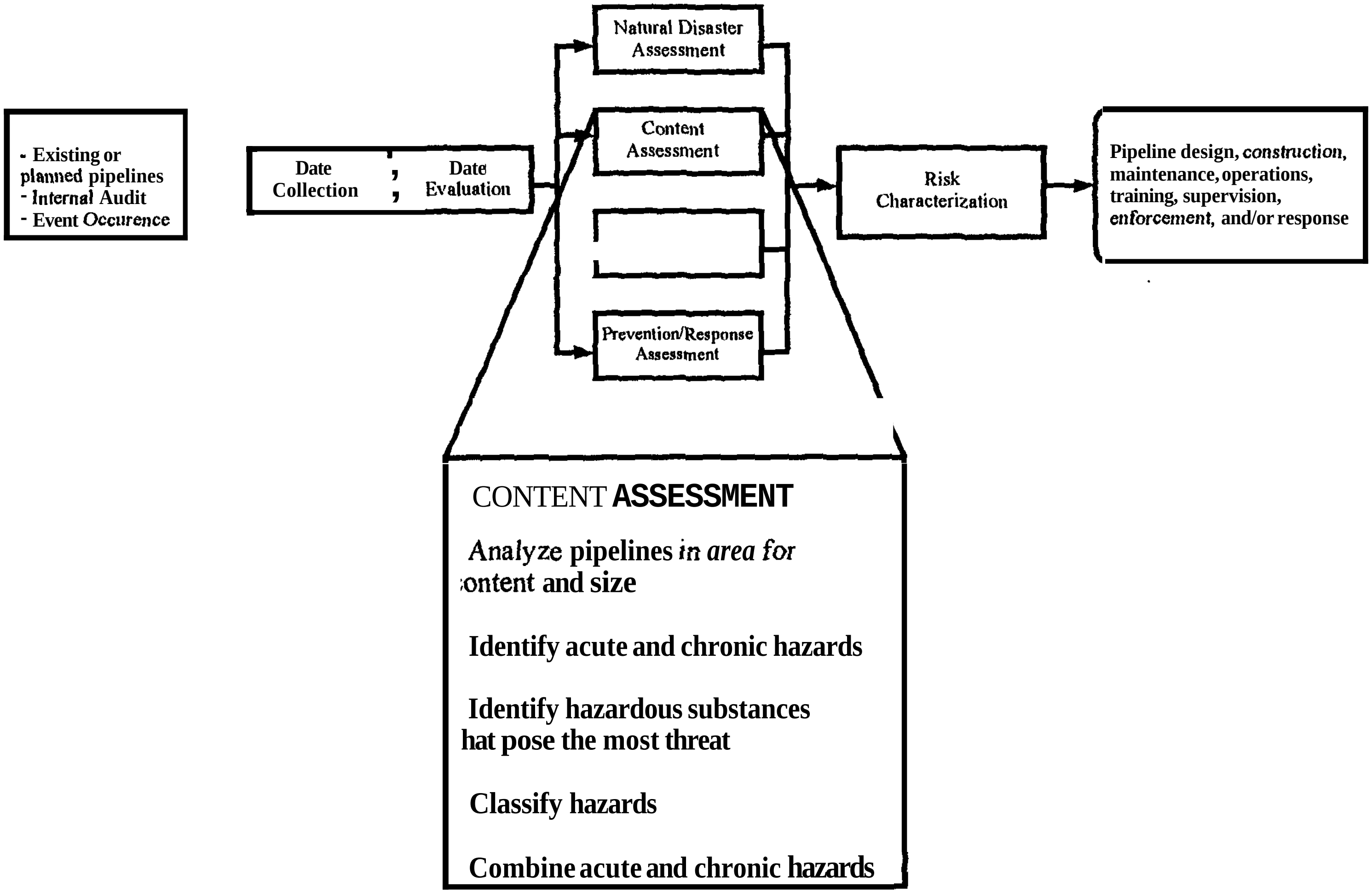


Figure 21: *Pipeline content* assessment

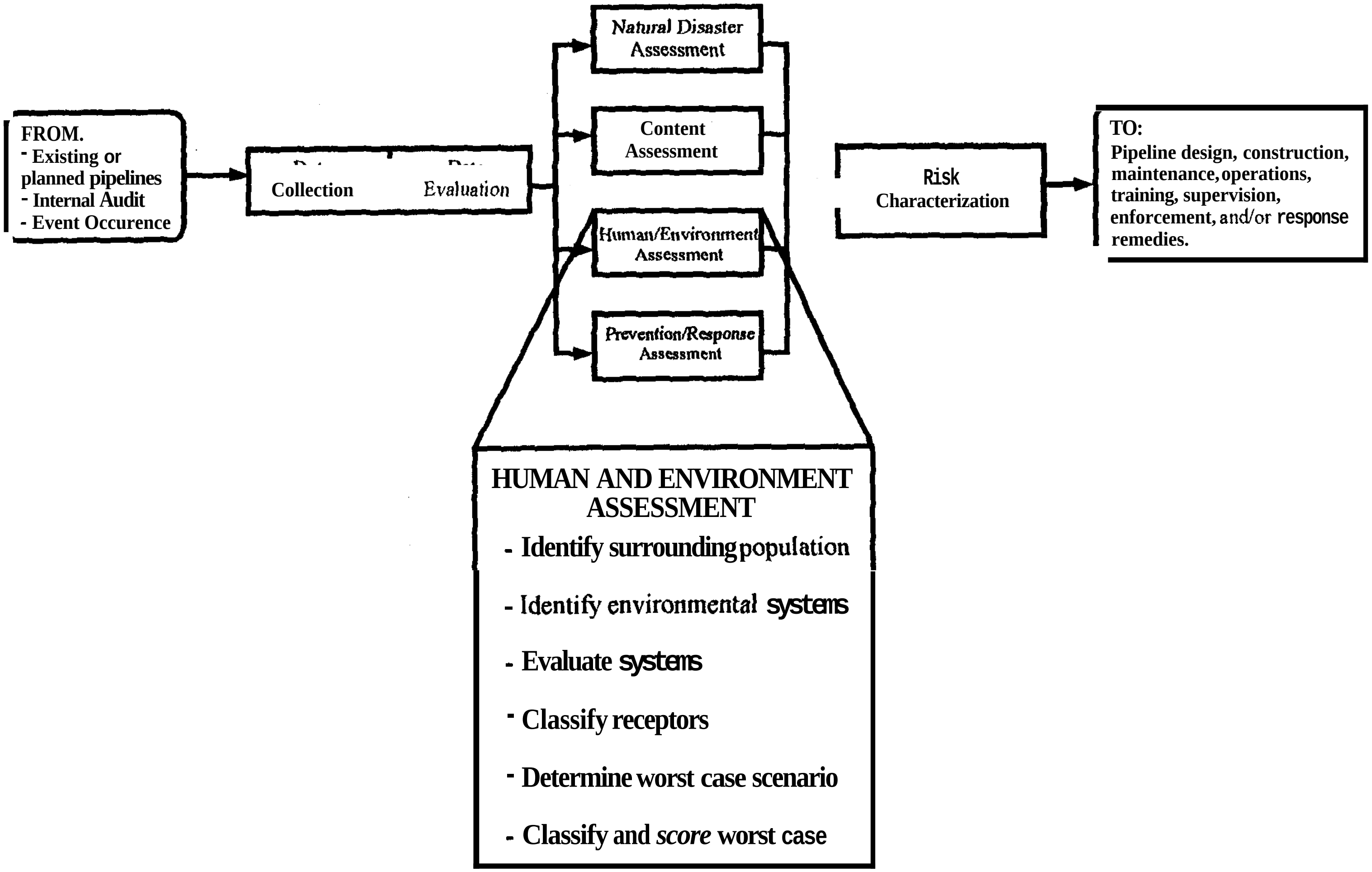


Figure 22: Human and environment *assessment*

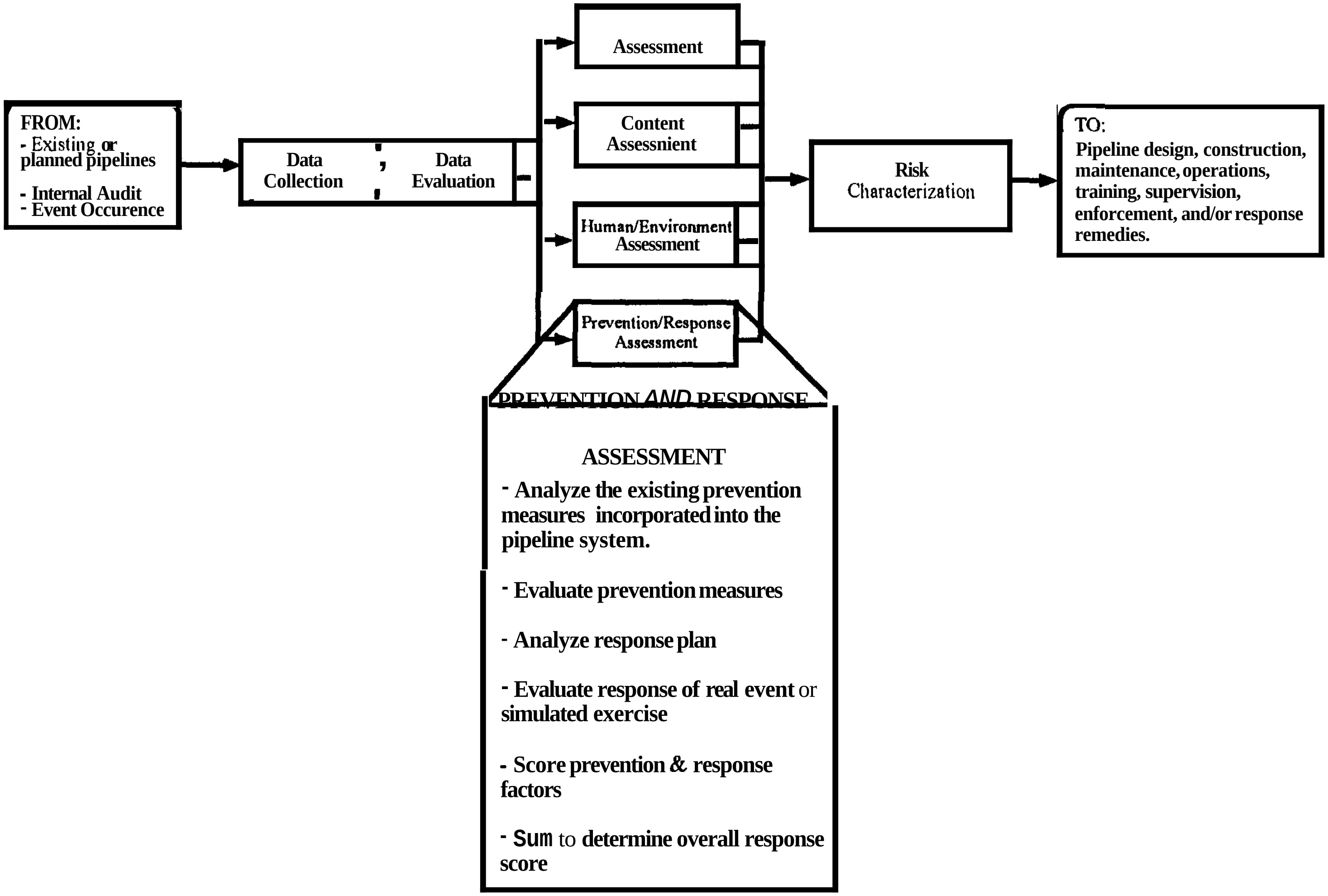


Figure 23: Prevention and response assessment

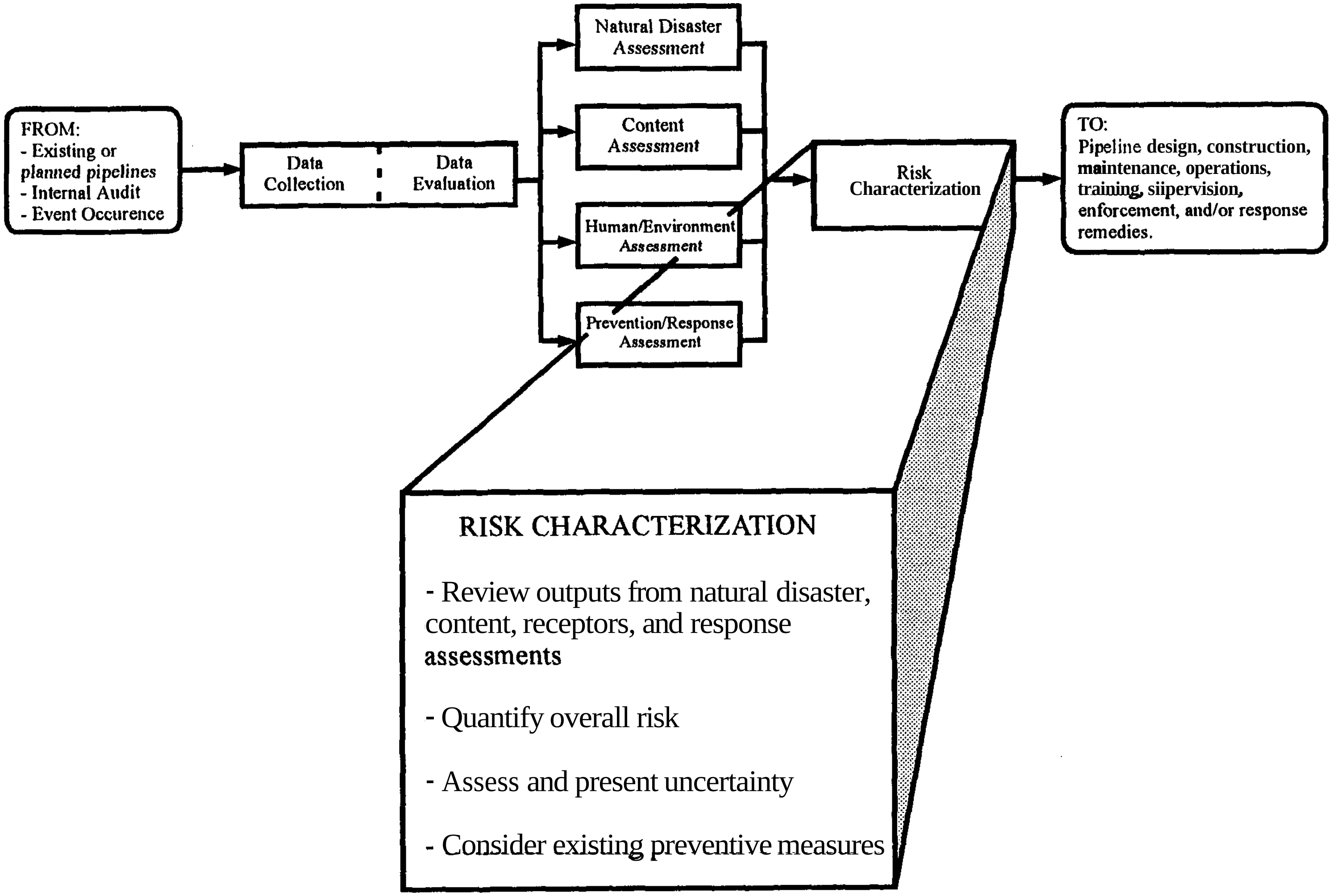


Figure 24: Risk characterization

Once the natural disaster events have been determined for a specified location, all natural disaster events for that area should be evaluated and categorized as to their individual probability of occurrence. This involves assigning a hazard quotient or risk rank to each natural disaster event, such as those developed by FEMA (1995a, b). The risk ranking system developed by FEMA is one of the broadest studies on natural disasters and will be used as the primary source for identifying natural disaster events in this report.

With natural disaster events analyzed for their probability of occurrence in a specified location, each risk rank should be summed to obtain a hazard index. This sum total of the risks for each natural disaster event can now be used to evaluate the overall risk of natural disaster occurrence for this given area. FEMA (1995a, b) approached this by developing a National Pipeline Risk Index (NPRI). The *NPRI* is calculated by summing the individual risk ranks for each natural event with a weighted factor, as demonstrated in the following equation :

$$NPRI = a(FRR) + b(ERR) + c(LSRR) + d(TSRR) + e(HURR) + f\ (Other)$$

where: a, b, ...f are weighted constants which must sum to 1.0.

FRR	Flood Risk Rank
ERR	Earthquake Risk Rank
LSRR	Soil Characteristics Risk Rank
TSRR	Tornadoes/Storms Risk Rank
HURR	Hurricane Risk Ranks
Other	Other Natural Hazards

The *NPRI* will be used in this study to determine the natural disaster risk score as shown in Table 2.

Researchers recommend that evaluators contact the Federal Emergency Management Agency (FEMA) for the latest NPRI values.

Table 2: NPRI and natural disasters score

NPRI	Natural Disaster Score
100 - 90	100
90 - 80	90
80 - 70	80
70 - 60	70
60 - 50	60
50 - 40	50
40 - 30	40
30 - 20	30
20 - 10	20
10 - 0	10

Pipeline Content Assessment

The diversity found in the types of materials transported by pipelines is vast, and assessing the hazards associated with these materials can be quite difficult. However, the assessment process can be partially simplified if the hazards are categorized as either acute or chronic. Acute or short-term hazards include those hazards that occur during or shortly after a one-time exposure. These types of hazards include fires, explosions, and sudden adverse effects that result from inhalation, ingestion, or dermal contact. Chronic or long-term hazards result from exposures over a long period of time. These hazards depend upon the material, the duration of each exposure, and the number of exposures (NIOSH and others 1985).

The assessment scheme that will be used to evaluate the risks associated with pipeline contents is shown in figure 25.

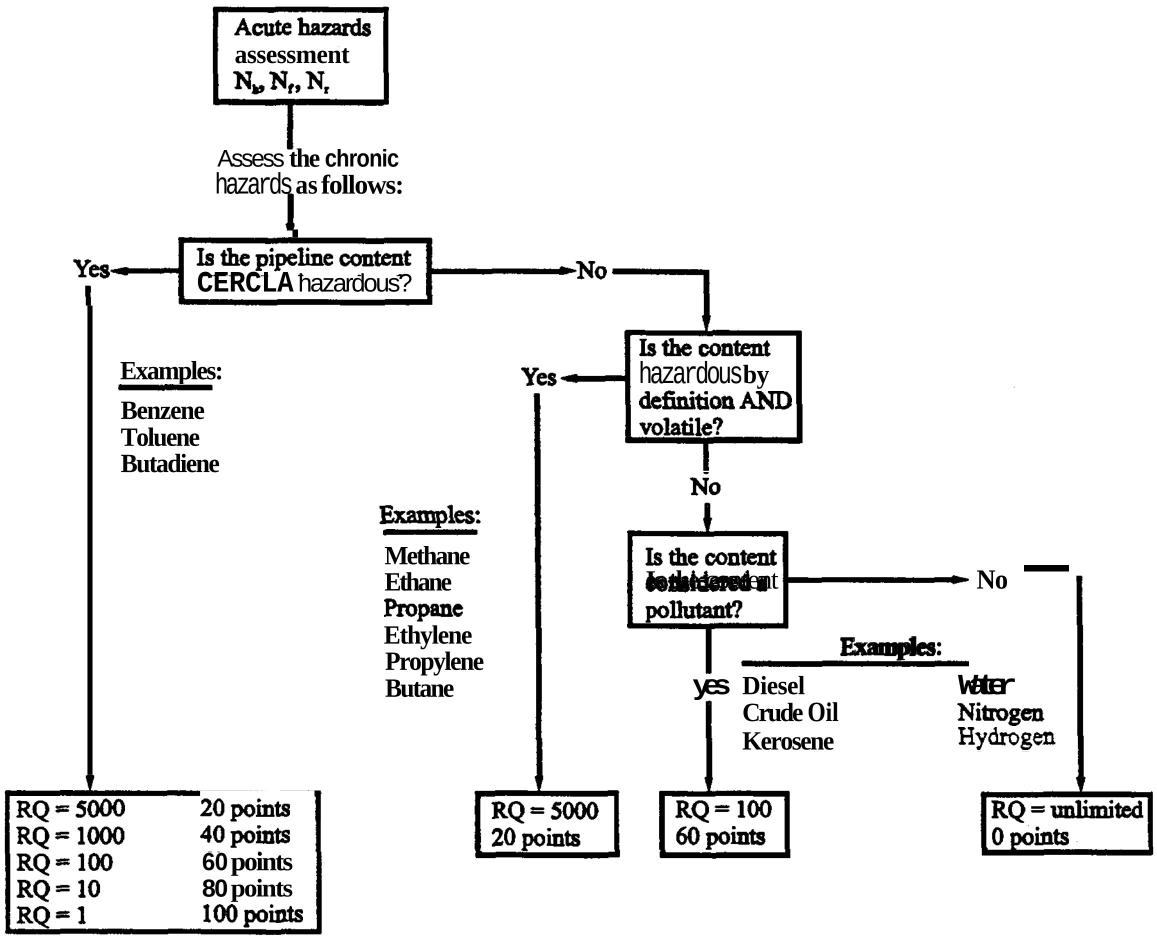


Figure 25: Content assessment scheme (adopted from Muhlbauer 1992, p173)

Acute (short-term) Hazards

The primary focus in determining the type of hazard associated with a pipeline, which is located in a specified area, depends upon the pipeline's content. The content of the pipeline is what poses the hazard. Regardless of whether the pipeline content is a liquid or gas, it must be assessed in terms of its health, flammability, and reactivity hazards. As discussed in the Prevention section of this report, response to a pipeline release is a vital element for reducing the impact of pipeline failures. Therefore, the hazards of pipeline contents should address the potential effects they can have on the response personnel. Muhlbauer (1992) points out that the National Fire Prevention Association's (NFPA) document NFPA 704 is an industry-accepted scale for rating pipeline contents. The scale rates the contents based on the threat to emergency response personnel. The potential threat is examined in terms of health, flammability, and reactivity hazards. NFPA (1990) designates the health, flammability, and reactivity hazards with the symbols N_h, N_f, and N_r, respectively. In the case that the pipeline's content is a mixture of more than one liquid and/or gas, or if pipelines located near other pipelines carry hazardous contents, the risks associated with the hazardous materials could be rated as a sum. However, it is recommended to evaluate each material and rank only the materials that pose the most threat.

Health Hazards. N_h

A health hazard, as stated in NFPA 704, is defined as follows (NFPA 1990, pp. 704-6):

> The likelihood of a material to cause either directly or indirectly, temporary or permanent injury or incapacitation due to an acute exposure by dermal contact, inhalation, or ingestion.

It is important to note that the health effects in this section are based on acute (short-term) hazards and not chronic (long-term) hazards. Long-term health effects will be covered in the Chronic Hazards section of this chapter.

The degree of health hazards associated with pipeline contents will be demonstrated by a numerical value from 0 to 4. The highest degree of health hazard will receive a score of 4 and the lowest 0. The health hazards are ranked and defined in NFPA 704 as follows (NFPA 1990, pp. 6-7):

N_h = 0 Materials that on short exposure, under fire conditions, would offer no hazard beyond that of ordinary combustible materials. This degree usually includes:

- materials whose LD_{50} (dose which will kill 50% of test animal population) for acute oral toxicity is greater than 2000 milligrams per kilogram (mg/kg);
- materials whose LD_{50} for acute dermal toxicity is greater than 2000 milligrams per kilogram (mgkg);
- dusts and mists whose LC_{50} (concentration which will kill 50% of test animal population) for acute inhalation toxicity is greater than 200 milligrams per liter (mg/L); and
- gases and vapors whose LC_{50} for acute inhalation toxicity is greater than 10,000 parts per million (ppm).

N_h = 1 Materials that, on short exposure, could cause irritation, but only residual injury, including those requiring the use of an approved air purifying respirator. This degree usually includes:

- materials that, under fire conditions, give off irritation combustion products;
- materials that, under fire conditions, cause skin irritation, but not destruction of tissue;
- materials whose LD_{50} for acute oral toxicity is greater than 500 milligrams per kilogram (mg/kg), but less than or equal to 2000 milligrams per kilogram (mgkg);
- materials whose LD_{50} for acute dermal toxicity is greater than 1000 milligrams per kilogram (mgkg), but less than or equal to 2000 milligrams per kilogram (mg/kg);
- dusts and mists whose LC_{50} for acute inhalation toxicity is greater than 10 milligrams per liter (mg/L), but less than or equal to 200 milligrams per liter (mg/L);
- gases and vapors whose LC_{50} for acute inhalation toxicity is greater than 5000 parts per million (ppm), but less than or equal to 10,000 parts per million (ppm); and
- materials that are moderate respiratory irritants or that cause slight to moderate eye irritation.

N_h = 2 Materials that, on intense or short exposure, could cause temporary incapacitation or possible residual injury, including those requiring the use of respiratory protective equipment that **has** an independent **air** supply. This degree usually includes:

- materials that give off toxic or highly irritation combustion products;
- materials that, under **normal** conditions or fire conditions, give **off** toxic vapors that lack warning properties;
- materials whose LD„ for acute **oral** toxicity is greater than 50 milligrams per kilogram (mgkg), but less than or equal to 500 milligrams per kilogram (mgkg);
- materials whose LD_{50} for acute dermal toxicity is greater than 200 milligrams **per** kilogram (mgkg), but less than or equal to 1000 milligrams per kilogram (mgkg);
- dusts and mists whose LC, for acute inhalation toxicity is greater than **2** milligrams per liter (mg/L), but less than or equal to 10 milligrams per liter (mg/L);
- any liquid whose saturated vapor concentration at 20 °C is equal to or greater than one-fifth ($^1/_5$) its LC_{50} for acute inhalation toxicity, if its LC„ is less than or equal to 5000 parts per million (ppm) and that does not meet the criteria for either degree of hazard 3 or degree hazard **4;**
- gases whose LC, for acute inhalation toxicity is greater than 3000 parts per million (ppm), but less than or equal to 5000 parts per million (pprn); and
- materials that cause severe but reversible respiratory, **skin,** or eye initation.

N_h = 3 Materials that, **on** short exposure, could cause serious temporary or residual injury, including those requiring protection from all bodily contact. This degree usually includes:

- materials that give off highly toxic combustion products;
- materials whose LD, for acute **oral** toxicity is greater than **5** milligrams **per** kilogram (mgkg), but less than or equal to 50 milligrams per kilogram (mgkg);
- materials whose LD_{50} for acute dermal toxicity is greater than **40** milligrams per kilogram (mgkg), but less than or equal to 200 milligrams per kilogram (mgkg);
- dusts and mists whose LC„ for acute inhalation toxicity is greater than 0.5 milligrams **per** liter (mg/L), but less than or equal to 2 milligrams per liter (mg/L);
- any liquid whose saturated vapor concentration at 20 °C is equal to or greater than its LC„ for acute inhalation

toxicity, if its LC, is less than or equal to 3000 parts per million (ppm) and that does not meet the criteria for degree of hazard **4;**

- gases whose LC, for acute inhalation toxicity is greater than 1000 parts **per** million (pprn), but less than or equal **to** 3000 parts per million (ppm); and
- materials that either **are** severely corrosive to skin **on** single, short exposure or cause irreversible eye damage.

N_h = 4 Materials that, **on** very short exposure, could cause death or major residual injury, including those that **are** too dangerous to be approached without specialized protective equipment. **This** degree usually includes:

- materials **that,** under normal conditions or under fire conditions, are extremely hazardous (i.e., toxic or corrosive) through inhalation or through contact with or absorption by the **skin,**
- materials whose LD„ for acute **oral** toxicity is less than or equal to ***5*** milligrams per kilogram (mg/kg);
- materials whose LD„ for acute dermal toxicity is less than or equal to **40** milligrams per kilogram (mg/kg);
- dusts and **mists** whose LC„ for acute inhalation toxicity is less than or equal to 0.5 milligrams per liter (mg/L);
- any liquid whose saturated vapor concentration at ***20*** °C is equal to or greater than ten times its LC_{50} for acute inhalation toxicity, if its LC_{50} is less than or equal to 1000 parts per million (ppm); and
- gases whose LC„ for acute inhalation toxicity is less than or equal to 1000 parts per million (ppm).

Flammability Hazards. (N_f)

Flammability is the ability a substance **has** to support combustion. **This** section addresses the degree of **this** ability. Since many materials will bum only under a certain set of conditions, it is important to consider the pipeline content's physical and chemical properties. NFPA **704** ranks the degree of flammability hazards for various materials based **on** the following (NFPA ***1990,*** p. ***8):***

N_f = 0 Materials that will **not** burn. **This** degree usually includes any material that will not burn in air when exposed to a temperature of 1500°F (815.5 °C) for a period of 5 minutes.

$N_f = 1$ Materials that must be preheated before ignition can occur. Materials in this degree require considerable preheating, under all ambient temperature conditions, before ignition and combustion can occur. This degree usually includes:

- materials that will burn in air when exposed to a temperature of 1500°F (815.5 °C) for a period of 5 minutes or less;
- liquids, solids, and semisolids having a flash point above 200 "F (93.4 "C) (i.e., Class IIIB combustible liquids); and
- most ordinary combustible materials.

$N_f = 2$ Materials that must be moderately heated or exposed to relatively high ambient temperatures before ignition can occur. Materials in this degree would not under normal conditions form hazardous atmospheres with air, but under high ambient temperatures or under moderate heating may release vapor in sufficient quantities to produce hazardous atmospheres with air. This degree usually includes:

- liquids having a flash point above 100°F (37.8°C), but not exceeding 200°F (93.4°C) (i.e., Class II and Class IIIA combustible liquids); and
- solids and semisolids that readily give off flammable vapors.

$N_f = 3$ Liquids that can be ignited under almost all ambient temperature conditions. Materials in this degree produce hazardous atmospheres with air under almost all ambient temperatures or, though unaffected by ambient temperatures, are readily ignited under almost all conditions. This degree includes:

- liquids having a flash point below 73°F (22.8°C) and having a boiling point at or above 100°F (37.8°C) and those liquids having a flash point at or above 73°F (22.8°C) and below 100°F (37.8°C) (i.e., Class IB and Class IC flammable liquids);
- materials that on account of their physical form or environmental conditions can form explosive mixtures with air and that are readily dispersed in air, such as dusts of combustible solids and mists of flammable or combustible liquid droplets; and

- materials that burn with extreme rapidity.

N_f = 4 Materials that will rapidly or completely vaporize at atmospheric pressure and normal ambient temperature or that are readily dispersed in air, and which will burn readily. This degree includes:

- flammable gases;
- flammable cryogenic materials;
- any liquid or gaseous material that is liquid while under pressure and has a flash point below 73°F (22.8°C) and a boiling point below 100°F (37.8°C) (i.e., Class IA flammable liquids); and
- materials that ignite spontaneously when exposed to air.

Reactivity Hazards, N_r

Some materials that are transported by pipelines are unstable under certain conditions. These materials may undergo violent chemical changes that release various degrees of energy if introduced to temperature changes, air, water, or other materials. The reactivity hazards listed in NFPA 704 are addressed only in terms of water reactivity. Therefore, contents that are believed to be reactive with other known substances should reflect an N_r value proportional to the likelihood of contact between the substances and severity of the potential reaction. For example, if two pipelines carry substances that are known to be reactive with each other in a high risk natural disaster area, then the potential of release for both lines and subsequent contact between the contents is high. Since the contaminants are known to react violently, the N_r value should be scored with 4. Some adjustments may be appropriate for depth cover, cover material, distance between pipe, and whether the pipes are buried or not buried. This modification step to the N_r value may become somewhat empirical; therefore, it should only be conducted after a thorough analysis.

The degrees of reactivity hazards are ranked in NFPA 704 by ease, rate, and quantity of energy release as follows (NFPA 1990, p. 9):

N_r = 0 Materials that in themselves are normally stable, even under fire conditions. This degree includes:

- materials that do not react with water;
- materials that exhibit an exotherm at temperatures greater than 300°C but less than or equal to 500°C when tested by differential scanning calorimetry; and
- materials that do not exhibit an exotherm at temperatures less than or equal to 500°C when tested by differential scanning calorimetry.

N_r = 1 Materials that in themselves are normally stable, but that *can* become unstable at elevated temperatures and pressure. This degree usually includes:

- materials that change or decompose on exposure to air, light, or moisture; and
- materials that exhibit an exotherm at temperatures greater than 150°C, but less than or equal to 300°C, when tested by differential scanning calorimetry.

N_r = 2 Materials that readily undergo violent chemical changes at elevated temperatures and pressures. This degree includes:

- materials that exhibit an exotherm at temperatures less than or equal to 150°C when tested by differential scanning calorimetry; and
- materials that may react violently with water or form potentially explosive mixtures with water.

N, = 3 Materials that in themselves are capable of detonation or explosive decomposition or explosive reaction, but that require a strong initiating source or that must be heated under confinement before initiation. This degree includes:

- materials that are sensitive to thermal or mechanical shock at elevated temperatures and pressures; and
- materials that react explosively with water without requiring heat or confinement.

N, = 4 Materials that in themselves are readily capable of detonation or explosive decomposition or explosive reaction at normal temperatures and pressures. This degree usually includes materials that are sensitive to localized thermal or mechanical shock at normal temperatures and pressures.

The overall acute hazard score is determined by multiplying the cumulative sum of health, flammability, and reactivity hazards $((N_h + N_f + N_r) \times 10$.

Chronic (long-term) Hazards

Chronic hazards are the exposure to harmful materials over a period of time. Although not usually considered an immediate threat, they can seriously affect the surrounding environment and endanger life or health.

Hazardous substances are defined in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) section 101(14). They are defined by reference to substances listed or designated under other environmental statutes. They include "hazardous wastes" under the Resource Conservation and Recovery Act (RCRA), "hazardous substances" defined in section 311 of the Clean Water Act, "toxic pollutants" designated under section 307 of the Clean Water Act, hazardous air pollutants listed under section 112 of the Clean Air Act, substances designated under section 102 of CERCLA which "may present substantial danger to public health or welfare or the environment," characteristic hazardous wastes under section 3001 of RCRA, and imminently hazardous chemical substances or mixtures that the Environmental Protection Agency (EPA) has addressed under section 7 of the Toxic Substances Control Act (TSCA) (Arbuckle and others 1993). The EPA has prepared a list of these substances to facilitate identification of CERCLA hazardous substances. The list of these substances is located at 40 C.F.R. part 302.

Included in 40 C.F.R. part 302 is Table 302.4 and Appendix B to Table 302.4. The quantity listed in the column "Final R Q for each substance in the table and appendix is the reportable quantity (RQ) for that substance. The RQ values are the amounts of harmful substances that require reporting after a release. These values are coded with the letters X, A, B, C, and D, which are associated with reportable quantities of 1, 10, 100, 1000, and 5000 pounds, respectively or 0.5, 4.5, 45.4, 453.6, and 2268 kilograms, respectively. The most hazardous substances have a RQ value of 1 pound (X) and the least hazardous substances have a RQ value of 5000 pounds (D). Therefore, the more hazardous the substance is, the less the reportable release quantity. The RQ values listed in Table 302.4 are in units of pounds and kilograms based on chemical toxicity, while the RQ values in Appendix B to Table 302.4 are in units of curies and becquerelies based on radiation hazard. Whenever the RQ values in the Table **302.4** and Appendix **B** to Table **302.4** are in conflict, the lowest RQ value dominates.

For cases where pipeline contents are specifically excluded fiom the EPA's RQ requirements under CERCLA, (i.e., petroleum, crude oil, and its fractions, natural gas, natural gas liquids, liquefied natural gas, and synthetic gases usable as fuel), a modification step must be implemented in order to quantify the risks.

Muhlbauer (1992) developed such a modification step by assigning "$RQ_{equivalent}$" classifications to the substances that are not assigned RQ values by the EPA. In this process the pipeline contents are first determined to be hazardous or non-hazardous. This is accomplished by determining if the pipeline content meets any one of the properties listed in the following four definitions (Dennison **1994,** pp. **49-50).**

1. Ignitability - A liquid, other than an aqueous solution containing less than **24** percent alcohol by volume with a flash point less than 60°C. A non-liquid that is capable, under standard temperature and pressure, of causing fire through friction, absorption of moisture or spontaneous chemical changes and, when ignited, bums so vigorously and persistently that it creates a hazard.
2. Corrosivity - A liquid that has a pH less than or equal to **2** or greater than or equal to **12.5.** A liquid that corrodes steel (SAE **1020)** at a rate greater than **6.35** mm per year at a test temperature of 55°C.
3. Reactivity - A substance that is unstable and readily undergoes violent change without detonation, reacts violently with water, forms explosive mixtures with water, generates toxic gases, vapors, or fumes when mixed with water or is capable of detonation or explosion.
4. Toxicity - A substance exhibits the characteristics of toxicity if the extract fiom a representative sample contains any of the contaminants listed in the Safe Drinking Water Act's list of National Interim Primary Drinking Water Regulation contaminants. (Dennison, pp. **49-51.)**

If the pipeline substance does not fall under any of the above four definitions and is specifically excluded from the EPA's list, the substance is deemed non-hazardous and is assigned an $RQ_{equivalent}$ of "unlimited." However, for those substances that are specifically excluded and do meet one or more of the above listed properties, a second step is initiated. This second step, as described by Muhlbauer (1992), involves categorizing the pipeline content as either volatile or non-volatile.

The chronic hazards associated with the highly volatile substances include the following (Muhlbauer 1992, p. 178):

1. residual hydrocarbons that pose the potential of being in soil or buildings, and pose a later flammability threat, and
2. the so-called "greenhouse" gases that are thought to be harmful to the ozone layer of the atmosphere.

These hazards are assigned $RQ_{equivalent}$ values of 5000 pounds or 2268 kilograms (class D).

The risks associated with the less volatile substances such as light crudes, kerosene, gasoline and diesel fuels, are addressed in the acute hazards assessment section and do not warrant further study under this chronic hazards section. However, the substances that are considered non-volatile should be assessed for their chronic (long-term) risks. The primary concern for the long-term risks associated with these substances is that they will contaminate the soil, surface waters, and/or groundwater. Therefore, it is recommended that these types of petroleum substances be given a $RQ_{equivalent}$ of 100 pounds or 45.4 kilograms (class B) rating (Muhlbauer 1992).

For cases when the pipeline content is a mixture, the hazardous components need only be considered. If two or more hazardous chemical agents are present, the RQ value should be based on the most hazardous component or, in other words, the worst case scenario.

With the RQ values defined for CERCLA's hazardous substances and the $RQ_{equivalent}$ method described above, the pipeline contents can be ranked based upon their RQ values. However, before the ranking process is described, it should be mentioned that the RQ values may need adjusting under certain circumstances. The following are a list of reasons that could warrant a change in a RQ:

1. For pipeline contents known to contain resistant, persistent, or recalcitrant compounds, it is suggested that the RQ values be assigned spill quantities of 100 pounds or 45.4 kilograms (class B), 10 pounds or 4.5 kilograms (class A), and 1 pound or 0.5 kilograms (class X), respectively. In some cases this may call for raising the severity of the RQ. For example, phenol is assigned a RQ of 1000 pounds or 453.6 kilograms by CERCLA; however, phenol is resistant in the environment and the RQ value may be adjusted to 100 pounds or 45.4 kilograms. These type of compounds are defined by Donnelly (1996) as follows:

   - Resistant Compounds - A chemical which is slowly degraded under adverse conditions, but may be degraded rapidly if conditions are optimized.
   - Persistent Compounds - A chemical that fails to undergo biodegradation under a specified set of conditions. A chemical may be inherently biodegradable yet persist in the environment.
   - Recalcitrant Compounds - A chemical that has an inherent resistance to any degree of biodegradation (Donnelly 1996, p. 3).

2. If the pipeline substance could form a toxic or flammable cloud of gas and travel off site, the RQ value should not be less than 10 pounds or 4.5 kilograms.
3. If the pipeline is proven to be incapable of releasing its content at the specified RQ, its RQ may be lowered to a less severe ranking. It is recommended that if a pipeline is thought to fall into this category, the release quantity should be based on, at minimum, a one-hour undetected leak. It should also take into account pipeline fluid decompression and pipeline drain down. (See California State Fire Marshal 1993.)
4. If the evaluator has strong evidence or knowledge of a pipeline substance being a worse hazard than is demonstrated by its RQ, the evaluator may revise the RQ to a more severe rating.

The chronic hazard scores associated with each determined RQ are shown in table 3.

Table 3: Risk rankings for RQs

RQ	Risk Ranking Score
Unlimited	0
5000	20
1000	40
100	60
10	80
1	100

The overall content hazards score is determined by adding the acute and chronic hazards together.

Overall Content Score = Acute Hazards + Chronic Hazards

Human and Environmental Systems Assessment

One of the major concerns with pipeline failures is that the pipeline content will contaminate a sensitive environment and/or endanger human life or health. To assess the risks associated with the potential receptors of released pipeline contents, this section addresses the existing human population and environmental systems that may be put at risk.

Human Population

To facilitate the analysis of the existing threat to human population, the Office of Pipeline Safety Rules class locations will be used. The class locations are determined by examining a defined area surrounding the pipeline. The area is to encompass any continuous one-mile (1.6 km) length of pipeline and is to extend 220 yards (201 m) on either side of the pipeline's centerline. This area is termed a class location unit and can be thought of as a 440 yard (402 m) by 1-mile (1.6 km) rectangle that is centered over the pipeline and slides along the pipeline's axis (see figure 26).

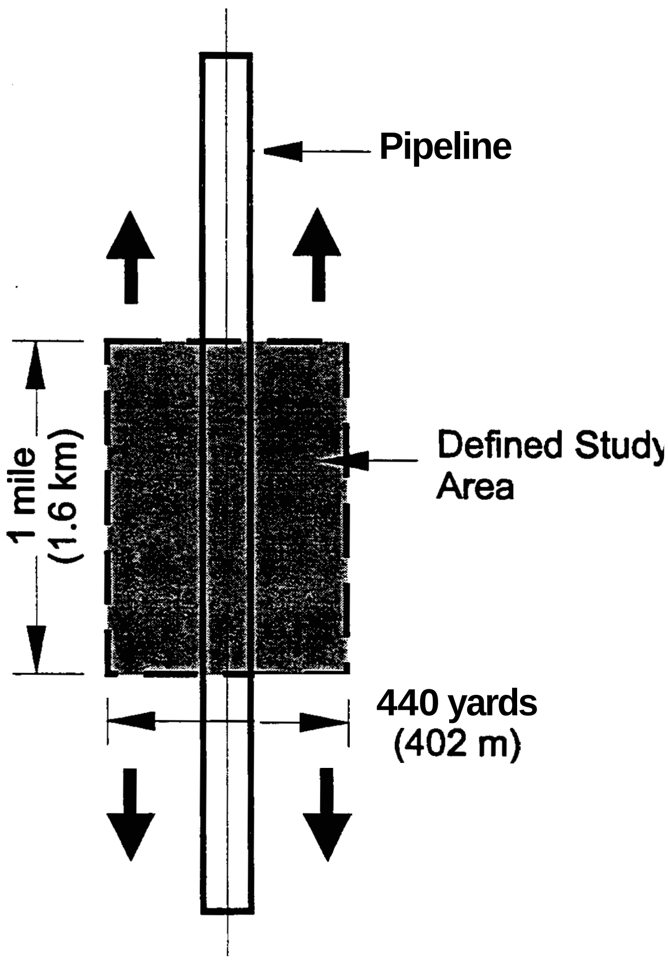


Figure 26: Defined area for OPS's class locations

The OPS's class locations for the existing human populations are defined as follows.

Class 1 • Any class location unit that has 10 or less buildings intended for human occupancy.

Class 2 • Any class location unit that has more than 10 but less than 46 buildings intended for human occupancy.

Class 3 • A class location unit that has 46 or more buildings intended for human occupancy;

o An area where the pipeline lies within 100 yards of either a building or a small, well-defined outside area (such as a playground, recreation area, outdoor theater, or other place of public assembly) that is occupied by 20 or more persons on at least 5 days a week for 10 weeks in any 12-month period.

Class 4 • A class location unit where buildings with four or more stories above ground are prevalent.

For cases when multiple dwelling units are encountered in a single building, each unit should be counted as a separate building intended for human occupancy.

GIS data bases, such as those developed by Claritas Inc. (1525 Wilson Blvd. Suite 1000, Arlington, Virginia), may be used as a source to obtain the necessary human dwelling information.

Environmental Systems

Environmental systems at risk in a pipeline release should be assessed for their physical, chemical, ecological, aesthetic, and social importance. This factor in the risk assessment calls for an extensive review of available data on the study area and may require site visits and further scientific studies.

The FEMA (1995 c) study on environmentally sensitive areas is one source that may be used in initially identifying these environmental systems (see figure 27).

Because of diversity in factors governing the importance of environmental systems, the following classification system is somewhat generalized and may call for value judgments. The OPS classification numbers 1 through 4 will be further expanded to simplify the process. The environmental systems to be evaluated will include any

Environmentally Sensitive Areas Rank

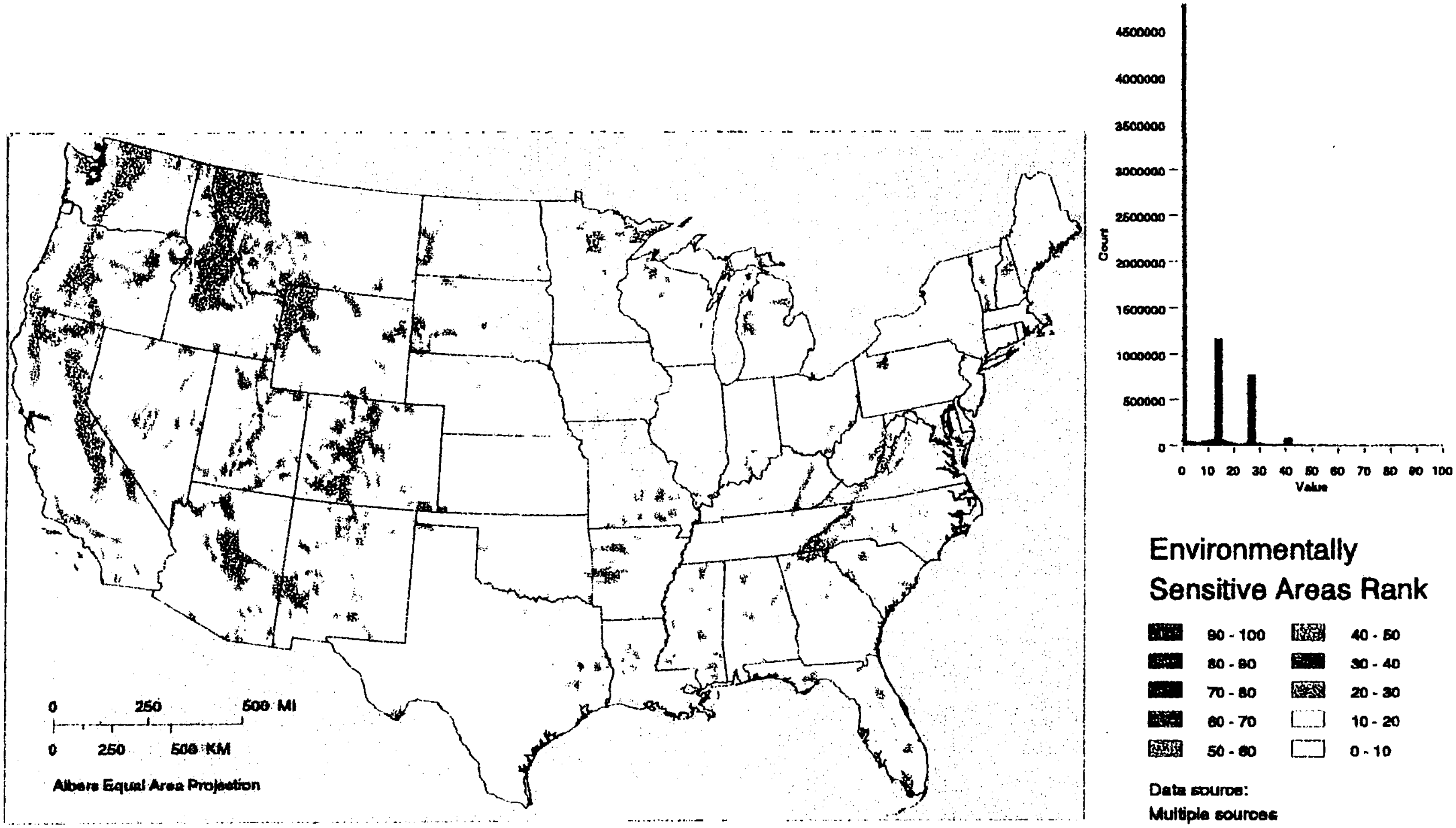


Figure 27: FEMA map of environmental sensitive areas (FEMA 1995c, Figure 5(a))

environmentally sensitive area within a one-mile (1.6 km) radius from the pipeline (line section) that could reasonably be expected to be contaminated.

A Class 4 environmental system will be assigned to any area where a pipeline release could cause long-term residual damage to a sensitive system or population. These type of areas will include the following:

- Any area where rare and endangered species reside, migrate, or cross on a regular basis. Species to be evaluated will include mammals, fish, birds, crustacean, plankton, benthos, and all other organisms.
- Any area that is a protected or sensitive ecological system (e.g., forests, marshes, wetlands, estuaries, surface waters, ground waters, sea grasses, rocky intertidal zones, shallow subtitle bottoms, beaches, mudflats, etc.).
- Any area where the release of crude oil, oil product, or hazardous substance/waste poses the potential of flowing down slope to a stream causing significant harm to humans, environmental systems, or water supplies downstream.
- Any area where the crude oil, refined oil product, or hazardous substance could penetrate glacial teal, karst topography, or other surfaces and impact subsurface water supplies/aquifers intended for public drinking water.
- Any area that is in or adjacent to navigable waters. (See 49 C.F.R 194.5 for navigable water definition.)

Environmental systems that are excluded from Class 4, but do have significant environmental importance because of their aesthetic, ecological, physical/chemical, or social reasons, should be addressed as Class 3 areas. Examples of these type of systems include:

- areas that contain a notable amount of game or non-game animals,
- areas that contain significant natural or managed vegetation,

- areas that contain resident or migratory birds,
- areas that are sport andor commercial fisheries,
- areas that have cultural or historical value,
- areas that are valued for aesthetic reasons, and
- areas where surface waters are located.

A Class 2 environmental system should be assigned to areas that have environmental importance, but where the pollutant will be highly diluted andor move through and restore quickly.

Those systems that are not considered environmentally important (i.e., isolated areas such as deserts, waste lands, etc.) should be addressed as Class 1 systems.

Researchers emphasize that the evaluator has leeway to make a value judgment over the classification of environmental systems. For example, if a pipeline transports a heavier than atmosphere gas, LPG or toxic material waste that could vaporize and form a toxic or flammable cloud of gas and travel out of the study zone, the evaluator should look at the environmental systems and human population outside of the study zone before classifying the system.

The points awarded to each classification system are shown in table 4. It is important to note that the classification for the entire study area is based on the worst case scenario for either human population or environmental systems; therefore, the points are not cumulative.

Table 4: Assessment score for human population and environmental systems

Class	Point Score
4	80
3	60
2	40
1	20

Prevention and Release Response Assessment

Prevention

Prevention measures that reduce the likelihood of pipeline failure will be assessed here by evaluating the design, construction, maintenance, operations, training, supervision, and enforcement aspects of the pipeline system. Each of these prevention aspects will be evaluated and scored separately. The overall prevention score will then be determined by summing the individual scores.

The design aspects of the pipeline system are scored as follows:

$$\textbf{Design} = \begin{cases} \bullet\ 0.0 \text{ if design aspects are below standards} \\ \bullet\ 0.5 \text{ if design aspects are at current standards} \\ \bullet\ 1.5 \text{ maximum if extralover - design was incorporated into the pipeline system} \end{cases}$$

If the pipeline falls into the design category of extralover-design, the evaluator is suggested to score the design by the following method.

$$\text{Design}_{\text{extra/over-design case}} = 0.5 + \text{each extralover - design aspect that reduces...}$$
$$\text{...the effects of a mode of impact}$$

Examples of these extra/over-design aspects are demonstrated in the following table. Please note that each design aspect is worth 0.25 points.

Modes of Impact Identified for a Tornado Event	**Design Measures to Reduce the Effects of the Mode of Impact**
Overstress in bridging and catenary type supports	The pipeline is below ground and does not have bridging or catenary type supports.
Scour to expose buried pipe	The pipeline is encased in concrete.
Extreme forces of wind	The pipeline is anchored or reinforced by above standard supports.
Debris carried by wind	The pipe material is stronger and thicker than what is standard or required.
Damage to protective covers	The pipe material or coating is above standards set for corrosion protection.

Construction aspects are assessed by determining if the pipeline system was constructed the way it was designed. This means: Was the system constructed with the materials and to the quality designated in the design specifications? Were qualified personnel used to construct the pipeline? Was the construction properly supervised by a qualified inspector?

$$\text{Construction} = \begin{cases} \bullet\ 0.0 \text{ if poor response} \\ \bullet\ 0.15 \text{ if average} \\ \bullet\ 0.25 \text{ if everything perfect} \end{cases}$$

Maintenance is assessed in terms of routine inspections, outlined procedures, and record keeping.

A. Routine Inspections: If routine maintenance inspections are scheduled and performed, add 0.3 points to the maintenance score.
B. Outlined Procedures: If maintenance procedures have been developed and are used for routine inspections and repairs, add 0.15 points.
C. Record Keeping: If maintenance inspections and repairs are documented and recorded for both routine and emergency situations, add 0.05 points.

$$\text{Maintenance} = A + B + C$$

The operation aspects of prevention will be assessed based on both control systems and emergency response procedures for natural disaster events.

A. Control Systems: If the pipeline operators are able to detect both small and large leaks in the pipeline, add 0.25 points to the operations score.
B. Natural Disaster Procedures: If specialized operating procedures have been developed and are available for natural disaster events, add 0.25 points.

Operations = A + **B**

The training aspects are assessed by first determining if all pipeline personnel have been trained to a level that matches their job functions and responsibilities. If they have, training is scored as follows. However, if they have not, the overall training score will be zero.

A. If all pipeline operators and maintenance personnel were trained with both classroom instructions and hands on practice, add 0.25 points to the operations score.
B. If pipeline personnel were trained in the prevention of pipeline failures resulting fiom natural disaster events, add 0.25 points.

Training = A + **B**

Supervision and enforcement are combined here to assure that all aspects of all of the prevention concepts are met appropriately. If the pipeline corporation has its own program to assure that standards and requirements in prevention are being met, score supervision and enforcement within the scale of 0 - 0.75 (0 indicates a poor or no program and 0.75 indicates a perfect program).

Response

In any pipeline release situation, two critical factors influencing the degree of human exposure and resulting environmental damage are the rapidity and effectiveness of the response. In the hectic minutes and hours after a spill occurs, the most important task for those in charge is to initiate pre-planned emergency response activities in the proper sequence: stop the pipeline release, minimize the danger of exposure to responders and the public, and immediately begin planned notification of industry response personnel and government/local agencies (Hann 1994).

Outside of an actual pipeline release emergency, the only way to properly assess the implementation of a response plan and the effectiveness of response is to conduct a simulated pipeline release exercise.

For the purposes of this assessment, an actual pipeline release emergency or simulated release exercise, whichever was conducted last, should be assessed on the factors listed below. It is suggested that if simulated data is used for the assessment, the pipeline release should be based on a worst case discharge.

The response factors to be evaluated are listed below and should be scored using the scales shown in table 5.

A. Was the release detected within the promised/required time frame ?
B. Was an effective notification of the required qualified personnel or alternates conducted?
C. Was the release prudently and effectively shut down?
D. Was the operator able to deliver the resources adequate for a worst case discharge to the necessary locations within the response zone?
E. Was the response effectively structured?
F. Did the response meet the objectives of the response plan?
G. Did response personnel work effectively with the response coordinator?
H. Did the response follow the response plan?
I. Did the plan generate a response to the level and with the personnel that was promised/required under Federal Response Plan Standards?
J. Was the response effectively managed as to the risk to humans and the environment?

The scale is set up so that a good response receives a higher score than a poor response.

Table 5: Response factor score

Response Factor	Score
A	0-0.45
B	0-0.15
C	0-0.45
D	0-0.30
E	0-0.15
F	0-0.30
G	0-0.15
H	0-0.15
I	0-0.30
J	0-0.60

The overall response score is determined by summing the individual response factors A through J.

Information on a pipeline's response plan may be obtained directly fiom the pipeline operator, the OPS/RSPA or the U.S. Coast Guard (USCG) National Strike Force headquarters in Elizabeth City, North Carolina.

It is important to note that many of the response factors depend upon the prevention concepts of construction, maintenance, operations, training, supervision, and/or enforcement. For example, block valves play a significant role in the response factor that deals with shutting down the pipeline release. This involves construction and maintenance concepts since the block valves must be properly constructed and maintained for them to operate effectively. It involves operations, training, and supervision because the block valves may require human action for manually operated systems. This requires the operators to be properly trained and supervised.

Risk Characterization

Once all of the **risk** assessment components have been analyzed and quantified, the overall **risk** score should be determined **as** follows:

$$\text{Risk Score} = \frac{\text{Natural Disaster Score} + \text{Content Score} + \text{Human \& Environment Score}}{1 + \text{Prevention \& Response Score}}$$

where	Natural Disaster Score	= 10 to 100
	Content Score	= 0 to 220
	Human & Environment Score	= 0 **to 80**
	Prevention & Response Score	= 0 to **7**

The overall **risk** score can then be used to determine what prevention andor response concepts, if any, need to applied to reduce the **risks.** The ranges are grouped fiom **high** to low **as** shown in table **6.**

Table **6:** **Risk** groups for overall **risk** score

Risk Score	Risk Group
400 - 200	High
200 - 50	Moderate
50 - 0	Low

The goal is to have the pipeline system ranked within the low **risk** group. Areas within the **high risk** group may lower their rating by increasing or adding preventive measures and response factors. ***Areas*** ranked in the moderate group may need only to add response factors to their response plans or upgrade their existing prevention measures.

It is important to note that the range of scores used in this risk assessment may be used or changed by the DOT-RSPA-OPS. The numbers used in this report for the risk assessment show the general importance of the various factors. It is up to the DOT-RSPA-OPS to make the final judgment on the range of the scores. The way the risk assessment is currently set up an area with a worst case scenario, which would involve the highest natural disaster, content, and human and environment scores, could be scored in the low risk group only by having the very best prevention and response.