BEFORE THE PUBLIC UTILITIES COMMISSION
OF THE STATE OF SOUTH DAKOTA

IN THE MATTER OF THE APPLICATION BY SCS CARBON TRANSPORT LLC FOR A PERMIT TO CONSTRUCT A CARBON DIOXIDE TRANSMISSION PIPELINE

DOCKET NO. HP22-001

Direct Testimony of Amy Cottrell
On Behalf of the Staff of the South Dakota Public Utilities Commission
June 23, 2023

EXHIBIT
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Q: Please state your name and business address.

A: Amy Cottrell, ERM, 1155 Perimeter Center West, Atlanta, Georgia, 30338

Q: Describe your educational background.

A: B.S., University of Wisconsin-Green Bay; Biology major, Environmental Science minor
M.S., Auburn University; Fisheries

Q: By whom are you now employed?

A: I have been employed by Environmental Resources Management, Inc. since March 2023.

Q: What work experience have you had that is relevant to your involvement on this project?

A: I have 10 years' experience as a fisheries biologist and aquatic ecologist for academic institutions and federal, state, and tribal governments in the Midwest, southeast, and pacific northwest. I have studied and implemented federal, state, and tribal regulations relating to aquatic and terrestrial natural resources, fisheries and wildlife management, and tribal treaty rights. I have experience working within the Migratory Bird Treaty Act, Endangered Species Act, Clean Water Act, Dingell-Johnson Act, Magnuson-Stevens Act, and state regulations. I have worked with United States Fish and Wildlife Services (USFWS), National Oceanic Atmospheric Administration (NOAA), Federal Energy Regulatory Commission (FERC), United States Army Corps of Engineers (USACE), Bureau of Indian Affairs (BIA), Environmental Protection Agency (EPA), Bureau of Land Management (BLM), United States Forest Service (USFS), Department of Transportation (DOT), and state natural resource agencies.

Q: What Professional Credentials do you hold?

A: Certified Fisheries Professional, American Fisheries Society
Endangered and Threatened species handling permit, USFWS

Q: What is the purpose of your testimony?

A: To provide an assessment of the completeness and adequacy of the Aquatic Impacts sections of the Summit Carbon Solutions Pipeline System application, specifically Section 5.4 – Aquatic Ecosystems. To assess that all reasonable ecological measures have been accounted for, and that remediation plans are wholistic and reasonable for aquatic ecosystems in the application. To provide professional recommendations of the proposed activities, mitigation measures and identify potential concerns assessed from review of the application.

Q: What methodology did you employ?

A: I reviewed the Supplement of the Application and associated components (Appendix 3 – Environmental Construction Plan, Appendix 6 – Project Mapping, Appendix 8 – Waterbody Crossings, Appendix 9 – Wetland Report, Appendix 10 – Threatened and Endangered Species Report, and applicant direct testimonies) and supplemental materials (applicant's responses to staff's first through fourth set of data requests) for completeness and accuracy, and consulted external resources, including:

- South Dakota Administrative Rules
- South Dakota Game, Fish and Parks (SDGFP) Fisheries Management Area Strategic Plans
- USACE Wetlands Delineation Manual
- U.S. Endangered Species Act species distribution and abundance list
- USGS National Land Cover Database
- Government agency rules in the Federal Register
- USFWS policy and regulations
- SDGFP Aquatic Invasive Species laws and regulations
- National Wetland Inventory database
- Reviewed published literature on ESA-listed species

Q: Did you review section 5.4 of Summit's Supplement of the Application?

A: Yes, I reviewed Section 5.4 – Aquatic Ecosystems of Summit's application and cross checked that with external resources as mentioned.

Q: Please summarize what information was included in section 5.4 of Summit's Supplement of the Application.

A: This section discussed wetlands, waterbodies, and fisheries that may be impacted by the Project either by direct crossing or proximity to. This includes wetland types present in the proposed Project area and the estimated acreage of wetlands impacted (Table 27), defined waterbody types and proposed Project waterbody crossing locations and methods (Table 28), fish presence data and most recent stocking events (Table 29), and documented Aquatic Invasive Species (AIS) within the proposed Project crossing locations (Table 30). Furthermore, Appendix 9 contains wetland delineation data. The Environmental Construction Plan (ECP; Appendix 3) contains methodology of pipeline construction and operation methods across wetlands and waterbodies, mitigation measures, and potential construction and operational impacts on wetlands, waterbodies, and fisheries. Appendix 10 contains the threatened and endangered species report.

Q: In your opinion, did Summit's Supplement of the Application adequately address ARSD 20:10:22:17 (Effect on aquatic ecosystems)? Please explain.

A: No; a complete impact analysis for construction and operation activities on the aquatic flora and fauna has not been provided yet. The construction design blueprints are provided in Appendix 3, though few operational procedures are discussed in text. Applicant identifies aquatic flora and fauna present in the proposed Project area but does not provide a complete and accurate impact analysis of the proposed facility on aquatic flora and fauna. This was addressed by Summit in their Response to Staff's Data Request 4-5 regarding wetland impacts but needs to be addressed for waterbodies and aquatic fauna.

Q: In your opinion, did section 5.4 of Summit's Supplement of the Application properly identify the potential impacts to wetlands and waterbodies?

A: Based on the information provided, I do not believe the potential impacts to wetlands and waterbodies have been addressed. The Applicant defines wetland types and lists their ecological services. Table 28 (Wetlands Impacted by the Project) provides the total wetland acreage impacted by construction and operation of the pipeline and access roads for each wetland type, provides data on temporary or permanent conversion, but does not separate these data out for individual wetlands. Table 29 (Named Waterbodies Crossed by the Project) of the Application provides named waterbodies that would be crossed, the construction methods used for each, and impacted acres within the waterbody, but does not identify potential impacts to the riparian zone and/or adjacent wetlands.

The Application does not define potential impacts of carbon dioxide released into the environment via construction and operation, but rather states there will be minimal to no negative impact. Discovery Letter 4 links Data Request 4-5 to excerpts from the Application, and provides references used for such excerpts. There are not enough empirical observational data available for CO_2 pipelines to claim that a CO_2 leak would be an unlikely event (*see* Exhibit_AC-2). Absolute statements should be reworded to reflect available data or removed. Impacts are not discussed in detail, for example, 'The depth of soil impacts likely will be minimal', and 'Groundwater impacts within the wetland are likely to be minimal'. While that may be true, the Applicant needs to define potential impacts regardless of the likelihood, and then provide mitigation measures in their ECP. There are currently no potential negative impacts or mitigation measures provided in the ECP. Statements of certainty like 'an accidental release from the pipeline will have little to no impact on the natural habitat' should be explained as to why that is the case and/or backed by scientific data.

Q: Do you agree with the mitigation measures Summit's plans to implement to minimize the potential impacts to wetlands and waterbodies?

A: Based on the information provided to date, I do not agree. Table 29 lists eight crossings using the horizontal directional drilling (HDD) method, and 19 crossings using the Wet Open Cut (WOC) method. Wetlands neighboring perennial and intermittent waterbodies should be crossed via HDD to significantly decrease negative impacts to aquatic flora and fauna. The HDD method of installing pipelines is well documented as having the least negative impact on environmentally sensitive areas, including wetlands. See Exhibit_AC-3 for more information.

Table 1 suggests the Applicant plans to obtain appropriate permits under Section 404 of the Clean Water Act for authorization to operate in and around waters of the US. Regarding wetlands, the application states, 'the Applicant will abide by all required mitigation measures regarding vegetation conversion on PFO wetlands.' For waterbodies, the applications states, 'the contingency plan will include instructions for monitoring (for drilling fluid loss) during the directional drill and mitigation in the event that there is a release of drilling fluids.

The Application contains very vague statements with no supporting documentation, e.g., 'All wetland areas within conservation lands or easements will be restored to a level consistent with any additional criteria established by the relevant managing agency.' The application needs to elaborate on what their restoration methods and post-construction monitoring will be and criteria/guidelines they will follow.

Waterbody impacts are listed in Section 5.4.2 – Fisheries – Aquatic Habitats and Communities. The application states, 'if a release occurs, the Project will initiate its emergency response procedures to shut down the mainline valves and restore the ROW where the release occurred'. The response to Staff's Data Request 4-6 states that a Draft Leak Emergency Response Procedure document has not yet been provided.

Q: Do you have any recommendations for additional mitigation measures in order to minimize impacts to wetlands and waterbodies? Please explain.

A: The ECP needs to describe how post-construction clean-up and monitoring will operate to avoid additional negative impacts to wetlands and waterbodies. I have no further recommendations on this as long as they follow FERC guidelines for wetlands and waterbodies (Exhibit_AC-4).

Table 28 should include impacts to the riparian zone and/or adjacent wetlands, especially given that wetland delineations are complete.

Q: In your opinion, did section 5.4 of Summit's Supplement of the Application properly identify the potential impacts to aquatic fauna?

A: Based on the information to date, I do not believe they have been properly identified. The categorical fishery water statuses of the named waterbodies are provided. According to the Fisheries Management Strategic Plan for the East River

Fisheries Management Area, the only crossed waterbody currently stocked is Brandt Lake, Lake County. This lake has common carp and sago pondweed.

The application only discusses ESA-listed, state species of concern, Aquatic Invasive Species (AIS), and native fish species that potentially use these waterbodies or wetlands and may be impacted by the project. The application does not include other native aquatic fauna, and it does not provide a complete prevention plan or mitigation measures for AIS.

Potential impacts provided in Section 5.4.2.1 (Potential Impacts to Fisheries) are not supported with references or expert analyses. The Applicant should provide the studies that Summit used to draw the following conclusions: 'Impacts such as increased suspended sediments will dissipate within hours of completion of the crossing.'; 'warmwater fish species are generally more resistant to the impacts of increased sediments than those of coldwater fisheries.'; and, 'The James River, Big Sioux River (Lincoln County crossing), Round Lake, and Brant Lake will all be crossed using HDD technologies and therefore require no in-water work and result in no disturbance of the waterbody banks or channels, and no suspension of sediments.'

Known impacts of HDD construction (i.e., unintentional drilling mud releases, increased sediment loading, and aquifer breaching) are not discussed.

Q: Do you agree with the mitigation measures Summit plans to implement to minimize the potential impacts to aquatic fauna?

A: Not completely. I do agree with the Applicant's plan to consult with USFWS and South Dakota Game, Fish, and Parks to assist with mitigation measures and obtain any necessary permits prior to Project construction. Also, species-specific baseline data are provided from 2017 electrofishing surveys at Highway 12 and Hitchcock crossing on the James River, 2016 gillnet surveys at Brandt Lake, most recent fish stocking records for waterbodies, and state wildlife action plan (SWAP)-listed Species of Greatest Conservation Need and ESA-listed species presence data are provided in Tables 24 (Probable Presence of Birds of Conservation Concern in the Project Area), 25 (Other State Listed Species in the Project Area), and 26 (Occurrence of Sensitive Species Near Project Footprint based on SDGFP Natural Heritage Data), and Appendix 10 - Table 2 (Federal and State Listed Threatened and Endangered Species Potentially Occurring with the Project Area). However, impacts to Pallid sturgeon are not fully addressed, and mitigation measures are not complete for aquatic fauna. These data are needed to help minimize or prevent potential negative impacts.

Q: Do you have any recommendations for additional mitigation measures to minimize impacts to aquatic fauna? Please explain.

A: Table 26 lists Pallid sturgeon presence as 'none', and Appendix 10 - Table 2 states, 'Suitable habitat for the Pallid sturgeon may be present in the Project area within the Big Sioux River'. This is anecdotal, as the USACE-mandated species assessment locations of the Missouri River Recovery Program (MRRP) did not include the upper Big Sioux River. Data are lacking for Missouri River tributary use, though research documents Pallid sturgeon often using large tributaries (e.g., Platte River; Hamel et al. 2014). Since these data are lacking, the HDD construction method for all waterbody crossings within the Big Sioux River system would be recommended in order to minimize impacts to the Pallid sturgeon. The Response to Staff's Data Request 4-15 states the Applicant will 'implement trenchless crossing methods of waterbodies that support suitable habitat for the Topeka shiner and Pallid sturgeon (Commitment made to USFWS)'. However, the Applicant does not provide a definition of suitable habitat for either species that is supported by either USFWS and/or published data. The Applicant should incorporate suitable habitat classifications into Table 28 and the updated table for wetland crossing methods.

The Application should contain baseline impact analyses and mitigation measures for Pallid sturgeon. The Project Impact Assessment column of Table 2 in Appendix 10 states, '…Therefore, the project will have no effect on this species'. I suggest that this statement be removed as it cannot be confirmed by data. I also suggest the Determination of Effect be changed from 'No effect' to 'Undetermined', and that the applicant follow up with a USFWS SD Ecological Services consultation for BMPs regarding the Pallid sturgeon range, suitable habitat, and additional protective measures that may be needed.

Baseline impact analyses and mitigation measures need to be included for non-ESA-listed or state-listed aquatic species.

Statements of certainty need to be backed by scientific data. More detail is needed when describing the impacts of sedimentation in streams (i.e., construction timeline, referenced timeline for suspended sediment from this type of construction). Warmwater fishes are not resistant to sedimentation in streams. e

Known impacts of HDD construction (i.e., unintentional drilling mud releases, increased sediment loading, and aquifer breaching) need to be defined.

The applicant should continue to consult with USFWS, and SDGFP to assist with mitigation measures throughout project development and during post-construction monitoring and remediation.

The invasive species prevention plan covers AIS preconstruction documentation and general equipment cleaning; however, the plan needs to include steps that are proven to be preventative, specifically for silver carp and bighead carp documented in the James, Vermillion, and Big Sioux rivers, and Eurasian water milfoil and curly leaf pondweed documented throughout the project area. Refer to the SDGFP

Aquatic Invasive Species Strategic Management Plan 2023 (AIS SMP; attached, Exhibit_AC-5) and consult with USFWS and SDGFP for additional guidance if needed.

Q: Are Summit's proposed construction techniques for waterbody crossings consistent with industry standard practices?

A: For the most part. Section 2.2.6 – General Construction Procedures states that 'the ECP (Appendix 3) identifies generally recognized BMPs that will be implemented to minimize and mitigate impacts, particularly to wetlands, waterbodies, and agricultural areas'.

Q: Do you have any concerns with the proposed waterbody crossing construction techniques proposed by Summit? If so, please explain and provide any recommendations you have for addressing your concerns.

A: Yes. Appendix 3 should provide more procedural detail on HDD and WOC crossing methods. The application should also describe when mitigation or remediation measures would be deployed. More detail is needed describing potential negative impacts of both HDD and WOC. For example, WOC construction would result in direct effects to sensitive waterbodies and potentially result in the "take" of state and federal protected species (e.g., Pallid sturgeon and Topeka shiner).

Post-construction remediation plans for negative impacts caused by construction vehicles and heavy equipment, and temporary and permanent roads need to be included for both HDD and WOC crossing methods.

HDD does present potential negative impacts to in-stream fauna via unintentional drilling fluid spills and aquifer breaching, known to occur during HDD construction. Some mitigation measures (e.g., 'energy dissipation devices may be used to help mitigate erosion while discharging suspended sediments into waters/wetlands') need to be further explained and address how aquatic fauna would be impacted during such measures.

Q: Did you review Summit's Horizontal Directional Drill (HDD) Contingency Plan?

A: Yes. The HDD Contingency Plan describes remediation steps to address an inadvertent release of drilling fluid. The Plan does not define potential negative impacts of an inadvertent release to the surrounding environment. The Plan does not define any additional potential risks of the HDD method (e.g., aquifer breaching, increased suspended sediment loading), nor does it provide any measures to mitigate potential risks. These need to be included.

Q: Did you review Summit's Spill Prevention, Control, and Countermeasures Plan (SPCC Plan)?

A: No. The applicant has not yet provided a Spill Prevention, Control, and Countermeasure (SPCC) Plan, which is utilized to help prevent the discharge of oil into waterbodies and surrounding shorelines. A properly defined SPCC Plan defines measures to help prevent spills from occurring, and control releases in the event a spill were to occur. A project-specific SPCC Plan would identify all potential waterbodies in relation to the Project and proposed project activities.

Q: Is Summit required by law or regulation to maintain an SPCC Plan for both construction activities and operation of the pipeline? If so, please explain what laws and regulations apply.

A: U.S. Pipeline and Hazardous Materials Safety Administration (PHMSA) regulations govern the spill responses for the pipeline during operation. This would typically be covered under an emergency response plan, which the Application states will be completed prior to commencing operation. The Applicant should develop a SPCC Plan for construction if it meets the USEPA requirements of (1) storing more than 1,320 gallons total of oil products (e.g., diesel fuel, gasoline, lube oil, hydraulic oil, etc.) at a location, and (2) if a release occurs, the oil products could reasonably be expected to discharge to navigable waters of the U.S. or adjoining shorelines. Based on the information provided on the application, I could not reasonably determine the applicability of this.

Q: Does this conclude your testimony?

A: Yes.

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Review

The environmental impact and risk assessment of CO_2 capture, transport and storage – An evaluation of the knowledge base

Joris Koornneef [a,*], Andrea Ramírez [b], Wim Turkenburg [b], André Faaij [b]

[a] Ecofys Netherlands B.V., Kanaalweg 16-A, 3526 KL Utrecht, The Netherlands
[b] Copernicus Institute, Faculty of Science, Utrecht University, Budapestlaan 6, 3584CD Utrecht, The Netherlands

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ABSTRACT

In this study, we identify and characterize known and new environmental consequences associated with CO_2 capture from power plants, transport by pipeline and storage in geological formations. We have reviewed (analogous) environmental impact assessment procedures and scientific literature on carbon capture and storage (CCS) options. Analogues include the construction of new power plants, transport of natural gas by pipelines, underground natural gas storage (UGS), natural gas production and enhanced oil recovery (EOR) projects. It is investigated whether crucial knowledge on environmental impacts is lacking that may postpone the implementation of CCS projects. This review shows that the capture of CO_2 from power plants results in a change in the environmental profile of the power plant. This change encompasses both increase and reduction of key atmospheric emissions, being: NO_x, SO_2, NH_3, particulate matter, Hg, HF and HCl. The largest trade-offs are found for the emission of NO_x and NH_3 when equipping power plants with post-combustion capture. Synergy is expected for SO_2 emissions, which are low for all power plants with CO_2 capture. An increase in water consumption ranging between 32% and 93% and an increase in waste and by-product creation with tens of kilotonnes annually is expected for a large-scale power plant (1 GW_e), but exact flows and composition are uncertain. The cross-media effects of CO_2 capture are found to be uncertain and to a large extent not quantified. For the assessment of the safety of CO_2 transport by pipeline at high pressure an important knowledge gap is the absence of validated release and dispersion models for CO_2 releases. We also highlight factors that result in some (not major) uncertainties when estimating the failure rates for CO_2 pipelines. Furthermore, uniform CO_2 exposure thresholds, detailed dose–response models and specific CO_2 pipeline regulation are absent. Most gaps in environmental information regarding the CCS chain are identified and characterized for the risk assessment of the underground, non-engineered, part of the storage activity. This uncertainty is considered to be larger for aquifers than for hydrocarbon reservoirs. Failure rates are found to be heavily based on expert opinions and the dose–response models for ecosystems or target species are not yet developed. Integration and validation of various sub-models describing fate and transport of CO_2 in various compartments of the geosphere is at an infant stage. In conclusion, it is not possible to execute a quantitative risk assessment for the non-engineered part of the storage activity with high confidence.

Contents

* Corresponding author. Tel.: +31 30 66 23 396; fax: +31 30 66 23 301.
E-mail address: j.koornneef@ecofys.com (J. Koornneef).

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1. Introduction

The capture, transport and storage of CO_2 (CCS) is currently being researched as a promising approach that may help to reduce anthropogenic CO_2 emissions. The basic idea is that CO_2 is captured, mainly from point sources in the industry and power sector, compressed, transported and injected in deep underground formations.

Several permits are required to realize CCS projects. Following the EU CCS Directive [1], commercial CO_2 capture, transport and storage activities *are highly likely to be subjected to an obligatory* Environmental Impact Assessment (EIA) to acquire these permits. The EIA is a procedural tool with the main goal to assess the environmental impacts of a proposed project. It is used to include environmental criteria into the decision making process for that project.

A complementary tool is the Strategic Environmental Assessment (SEA). This tool is used to facilitate policy decisions on a strategic level. Strategic policy plans are obligated to include a SEA when they contain the consideration or appointment of possible locations or routes of EIA obligated activities. Such considerations or appointments are typically the subject of spatial plans formulated by national, regional or local governments [2–4].

According to Finnveden et al. [3], both environmental assessments can be characterized by three elements: institutional arrangements, the procedure and applied methods. A fourth element would be the environmental impacts assessed in the procedure, i.e. the content of the environmental report or Environmental Impact Statement (EIS). In recent literature, increasingly attention has been given to the role of EIA and SEA procedures in the implementation of CCS activities. Zakkour and Haines [5] identify Environmental Impact Assessment (EIA) as a key process in regulatory and permitting procedures and attribute a role for SEA procedures to contribute to the formulation of CCS deployment policy. Mace et al. [6] identify EIA and SEA requirements in the implementation of CCS activities as a regulatory challenge to policymakers. In Koornneef et al. [2] parts of this challenge for administrative bodies and project initiators regarding the institutional arrangements and procedural elements of both assessments have been addressed [2]. There, the focus was aimed towards the identification of the scope of both procedures, yielding insight in the operational, technical, location and strategic alternatives that should be investigated in the assessments. No detailed attention was paid to the environmental impacts to be investigated in the assessments.

The challenge remains to take the existing assessment frameworks that are used in analogous EIAs and apply them on CCS activities. This includes the possibility to use existing tools to investigate the environmental consequences of CCS activities. Recently, this issue has also been addressed in a IEA GHG[1]

[1] IEA GHG = Greenhouse Gas R&D programme of the International Energy Agency.

Nomenclature

ASU	Air Separation Unit
BAT	Best Available Technology
BREF	Best Available Technology Reference Documents
CCS	Carbon Dioxide Capture (Transport) and Storage
$DeNO_x$	Installation to remove NO_x from flue gases
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EOR	Enhanced Oil Recovery
ESP	Electrostatic Precipitator
FEP	Feature, Event, Process
FGD	Flue Gas Desulphurization
FGR	Flue Gas Recycling
GC	Gas cycle
Gt	Gigatonne
HSE	Health, Safety and Environment
HSS	Heat Stable Salt
IEA	International Energy Agency
IGCC	Integrated Gasification Combined Cycle
IPPC	Integrated Pollution Prevention and Control (Bureau/Directive)
kt	Kilotonne
kWh	kilowatt-hour
MDEA	Methyldiethanolamine
MEA	Monoethanolamine
MHI	Mitsubishi Heavy Industries
MJ	Megajoule
Mt	Megatonne
NGC	Natural Gas Cycle
NGCC	Natural Gas Combined Cycle
PC	Pulverized Coal
PM	Particulate Matter
ppm	parts per million
(Q)RA	(Quantitative) Risk Assessment
S(N)CR	Selective (Non) Catalytic reduction
SCR	Selective Catalytic Reduction
SEA	Strategic Environmental Assessment
SOFC (+GT)	Solid Oxide Fuel Cell (+Gas Turbine)
t	Tonne
UGS	Underground Gas Storage
VOC	Volatile Organic Compounds
WGS	Water Gas Shift
WWT	Waste Water Treatment
yr	Year

programme study which was, next to reviewing international procedural EIA frameworks, oriented towards the identification of information requirements and possible knowledge gaps on environmental consequences when these frameworks are applied to CCS activities [7]. The results of that study indicate the presence of gaps in environmental guidelines, standards and knowledge required for the execution of environmental assessments. The study concludes that additional knowledge is required on:

- The environmental performance of large-scale CO_2 capture systems;
- The modeling of the dispersion of supercritical CO_2 releases;
- The probability, size and environmental consequence of CO_2 leakages resulting from CO_2 storage.

Especially the latter turns out to be a primary concern in the public debate about an onshore CO_2 storage project, the Barendrecht project, in a small depleted gas field in the Netherlands [8]. This project has been cancelled and the results of the EIA turned out to be of very high importance for the (local) governmental bodies involved in the decision making process for that project. The environmental consequences and the way they are assessed and presented in an EIA procedure may be a pivot in the further deployment of CCS, especially when storage takes place onshore.

Information in environmental assessments is often captured in the form of environmental indicators. Such indicators can be used to report on complex phenomena in a simple form that in turn can be used in decision making [9]. In this study, specific attention is paid to quantified indicators that are or may be used to report on the environmental consequences of CCS activities.

The goal of this study is to identify and characterize known and new environmental interventions associated with CCS activities that are typically addressed in EIA procedures. We screen state-of-the-art literature on available and missing quantitative information (and indicators) on environmental impacts and risks of CCS activities. In addition, it will be investigated whether crucial environmental information is lacking that may postpone the implementation of CCS projects.

Specific emphasis is put on knowledge that should be available if CCS is to be implemented on a large-scale in the short-term. This focuses this study towards technologies that are available at present or in the near future.

2. Approach and research method

In order to fulfill the goal of this study we carried out a review of documents related to analogous EIA procedures and EIA procedures for CCS activities as well as scientific literature on CO_2 capture, transport and storage. Analogous EIA procedures were reviewed for three distinctive process steps of a CCS project: the power plant with capture, the transport and finally the underground storage of CO_2. The selected analogues include the construction of new power plants, transport of natural gas by pipelines, underground natural gas storage (UGS), natural gas production and enhanced oil recovery (EOR) projects. For a comprehensive list of the reviewed EIA procedures see [2,10] and the supplementary material provided online. In addition, EIA procedures for CO_2 storage projects were reviewed.

With this information, the following research steps were carried out:

- Identify and characterize quantitative environmental indicators reported in EIA documents for CCS and analogous activities;
- Discuss new environmental information, possible indicators and assessment tools for CCS activities;

The results of these research steps are presented in the following sections. The structure of the article is as follows. In Section 3, 4 and 5 we assess the environmental information on power plants equipped with (and without) CO_2 capture, its transport by pipelines and its storage in geological formations, respectively. In Section 6 we compare the significant risks of CCS activities. In Section 7 we summarize our main findings and we conclude with several recommendations for further research and regulatory efforts.

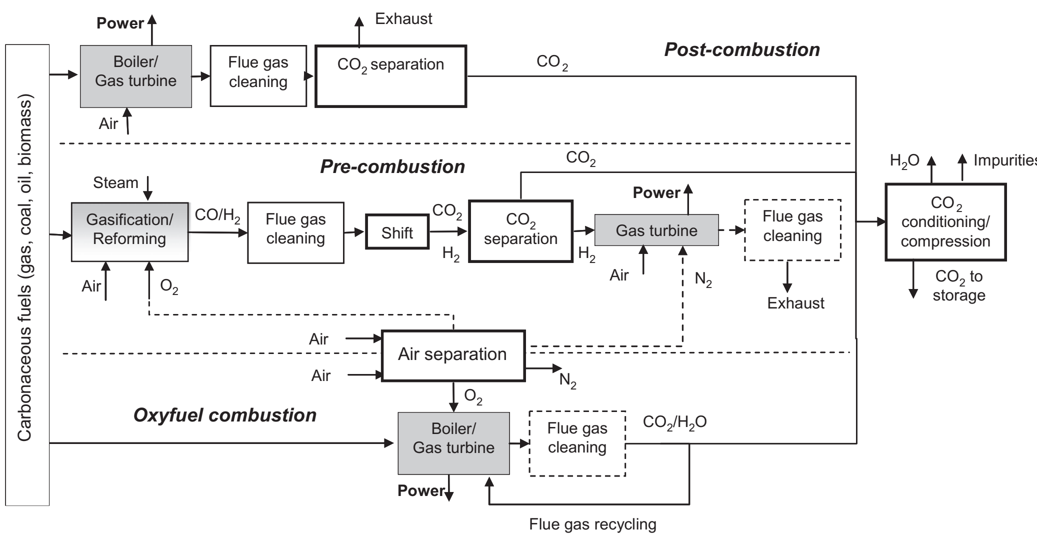


Fig. 1. Simplified overview of the three CO_2 capture systems for power plants: post-, pre- and oxyfuel combustion. Grey components indicate power generation processes. Components with highlighted borders indicate processes causing a drop in generating efficiency. Components with dashed borders indicate optional processes. Note that natural gas reforming using steam is an endothermic process and therefore not a power generation process, hence the altered shading.

3. Power plants with CO_2 capture

When assessing the environmental consequences of a power plant it is important to consider the construction, operational and decommissioning phase. The reviewed EIAs focus on the operational phase of the power plant, see [11–16]. Earlier studies have indicated that environmental impacts that can be attributed to the infrastructure of CCS projects are limited compared to the impacts attributable to the operational phase [17–19]. Here we focus on the operational phase and the environmental themes that are expected to be affected the most by equipping power plants with CO_2 capture, being: energy, atmosphere, water, waste and by-products, resource consumption and external safety. This information is needed on the short term to allow the permitting of CCS projects. We thus focus on possible environmental impacts of CO_2 capture technologies that may be implemented at power plants in the near-term and compare the performance of power plants equipped with CO_2 capture with reference power plants without CO_2 capture. We take into account the three main capture systems for the removal of CO_2 depicted in Fig. 1: post-combustion, pre-combustion and oxyfuel combustion.

Post-combustion CO_2 capture encompasses the removal of CO_2 from the flue gas of a combustion process. This can be (pressurized) combustion in a boiler or gas turbine. CO_2 is removed by a solvent that chemically or physically traps the CO_2. A combination of both mechanisms is also possible. The CO_2 can then be removed from the solvent by heating or a pressure reduction. The current focus is on using chemical absorption as separation technique. The chemical absorption technologies that we reviewed include technologies using alkanolamines, such as monoethanolamine (MEA), Fluor's Econamine FG+ and MHI's[2] KS-1 solvent. Other technologies reviewed are based on absorption using chilled ammonia (NH_3), alkali salts (i.e. potassium carbonate - K_2CO_3) and amino salts. The post-combustion system can be applied to various energy conversion technologies. In this study, we review its application to Pulverized Coal (PC) and Natural Gas Combined Cycle (NGCC).

Pre-combustion CO_2 capture is aimed to remove the CO_2 before the fuel is combusted. This requires the fuel to be gasified or reformed into a syngas, which comprises mainly CO, H_2O, H_2 and CO_2. The water gas shift reaction catalytically shifts CO and H_2O to H_2 and CO_2. The CO_2 can then be removed, with chemical and physical solvents, adsorbents and membranes. The H_2 can be used for power production in a gas turbine. The current focus is on using chemical or physical (or a combination) solvents to separate the CO_2. The energy conversion technology that is envisaged using pre-combustion that is mainly investigated in this study is the Integrated Gasification Combined Cycle (IGCC) power plant. We take into account IGCC systems based on Shell, GE and E-Gas gasifiers with pre-combustion capture based on Selexol and MDEA (methyldiethanolamine).

Oxyfuel combustion is based on denitrification of the combustion medium. The nitrogen is removed from the air through a cryogenic air separation unit (ASU) or membranes. Combustion thus takes place with nearly pure oxygen. The effect of which is a flue gas containing mainly CO_2 and water. The CO_2 is purified by removing water and impurities. The current focus is on using cryogenic air separation as the oxygen production technique. The energy conversion technologies that have been reviewed in this

Table 1
Simplified overview of energy conversion and CO_2 capture efficiencies of power plants equipped with various CO_2 capture technologies, after [20].

Capture process	Conversion technology[a]	Generating efficiency[b](%)	Energy penalty of CO_2 capture (% pts.)	Capture efficiency (%)
Post-combustion (chemical absorption)	PC	30–40	8–13	85–90
	NGCC	43–55	5–12	85–90
Oxyfuel	PC	33–36	9–12	90–100
	GC and NGCC	39–62	2–19	50–100
Pre-combustion	IGCC	32–44	5–9	85–90
	GC	43–53	5–13	85 ~ 100

[a] PC = Pulverized Coal, NGCC = Natural Gas Combined Cycle, GC = Gas Cycle, IGCC = Integrated Gasification Combined Cycle.
[b] Efficiencies are reported based on the Lower Heating Value (LHV) and assuming a CO_2 product pressure of 11 MPa.

[2] Mitsubishi Heavy Industries.

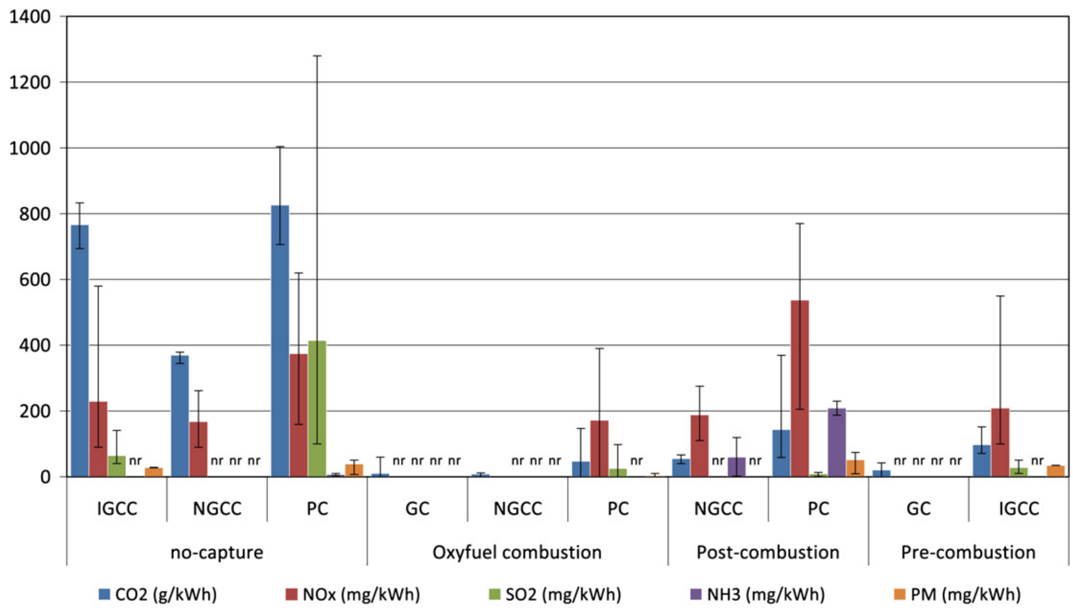


Fig. 2. Atmospheric emissions of substances CO_2, NO_x, SO_2, NH_3 and particulate matter for various conversion technologies with and without CO_2 capture, adapted from [24]. Ranges indicate maximum and minimum values reported. Note that emissions are based on various fuel specifications and on the configuration and performance of the power plant and CO_2 capture process. 'nr' = 'not reported'.

study more extensively are rather conventional PC and NGCC power plants.

3.1. Energy

CO_2 capture and compression requires energy which results in an energy penalty for the power plant, reducing the net conversion efficiency of the power plant. In Fig. 1, the processes are shown per capture system that are added to the power generation concepts and through their demand for thermal, chemical or electrical energy result in an efficiency penalty. The energy penalty varies with capture system and technologies, see Table 1. A detailed review of the thermodynamic performance of power plants equipped with CO_2 capture technologies is presented by Damen et al. [20].

3.2. Atmosphere

Key atmospheric emissions assessed in EIAs for biomass and coal fired concepts are CO_2, NO_x, SO_2, HCl, HF, VOC, PM, Hg, Cd, and other heavy metals. Additionally, the emission of NH_3 slip from flue gas cleaning and dust during the handling of the fuel are assessed. For gas fired concepts CO_2 and NO_x are the most dominant atmospheric emissions. Equipping power plants with CO_2 capture technologies affects both the formation and fate of many of these emissions. Tzimas et al. [21] reviewed NO_x and SO_2 emissions in fossil fuel fired power plants equipped with CO_2 capture and found a trade-off in atmospheric emissions. A detailed review of the effect of post-, pre- and oxyfuel combustion CO_2 capture on the substances NO_x, SO_2, VOC, PM and NH_3 is provided in [21–24]. The reported emission factors per kWh for these substances are presented in Fig. 2. The main effects of CO_2 capture on atmospheric emissions are summarized below per capture system.

3.2.1. Post-combustion

In Fig. 1, it is shown that the CO_2 capture process is situated after the flue gas cleaning section. Depending on the type of solvent that is used, impurities need to be removed from the flue gas in order to limit operational problems. Examples are solvent degradation, foaming and fouling. Impurities that need to be removed are typically acid gases (NO_x, SO_x, HCl and HF) and particulate matter (PM). Power plants equipped with CO_2 capture should thus be equipped with highly efficient flue gas desulphurization (FGD), $DeNO_x$ installations and electrostatic precipitators (ESP) and/or fabric filters to remove PM. Also, the flue gas typically requires cooling before it is processed in the CO_2 capture installation. In the CO_2 capture process also some of these substances are partially removed, see Table 2.

Depending on the increase in primary energy use due to the capture process, the net result may be that non-CO_2 emissions to air increase per kWh, like NO_x. For some post-combustion variants additional atmospheric emissions are expected. This encompasses the emission of solvent or degradation products of the solvent. This may be NH_3 for the chilled ammonia process [29–31]. The

Table 2
Overview of removal efficiencies of flue gas conditioning and post-combustion capture technologies removing atmospheric substances.

Sorbent/power plant	Removal efficiency[a] (%)		Remarks
	Flue gas conditioning	Reduction in capture process	
Amine based MHI KS-1/PC power plant	PM: 40% and 50% SO_2: > 98% HCl and HF: ~complete	PM: 40–60% SO_2: "almost all" NO_x: 1–3%.	Cooling and desulphurization with NaOH scrubber [25,26].
Alkanolamines/PC power plant	–	SO_2: 40–85% uptake of total sulphur NO_x: 0.8%	No additional flue gas conditioning installed [27,28]

[a] This indicates the extra removal of impurities compared to existing flue gas cleaning equipment and does not take into account the efficiency penalty.

Box 1. Potential environmental impacts of amines and their degradation products.

Amine based solvents used for post-combustion capture are usually produced from basic chemicals like ammonia, methanol and ethylene oxide. MEA is distilled from a mixture of MEA, DEA and TEA (mono-, di- and tri-ethanolamine) and produced in a batch mode from ethylene oxide and ammonia. Amines and degradation products are found to be emitted by the stack, causing potential environmental impacts. MEA (2-aminoethanol) is emitted in small quantities (1–4 ppmv) due to entrainment in the scrubbed flue gas. This corresponds to 40–160 t/yr for a plant capturing 1 Mt per annum, but is possibly lower for capture facilities with mitigation measures implemented [44].

The toxicity of MEA is well documented and exposure guidelines are set [45]. However, research towards understanding chronic exposure effects and other toxicity end-points seems to be lacking. According to the National Research Council [45], no relevant studies were identified for the carcinogenicity of MEA.

Another potential concern that was already raised by Rao et al. [33] is the formation of (carcinogenic) nitrosamines, nitramines and amides that are products of the reaction of ethanolamines and atmospheric oxidants (e.g. NO_x) under the influence of sunlight. Unlike diethanolamine, MEA has not been found to form a stable nitrosamine [44,45].

There is growing awareness on the possible environmental impacts of CO_2 capture and both desktop studies as measurement campaigns are deployed to address potential concerns [46]. Several are listed below:

- In 2007, the Norwegian Institute for Air Research (NILU) initiated a project to study the effects of amine emissions to the environment. The amines studied are MEA, AMP, MDEA and piperazine (MEA (2-aminoethanol): $H_2NCH_2CH_2OH$; AMP (2-amino-2-methyl-1-propanol): $(CH_3)_2C(NH_2)CH_2OH$; MDEA (2,2′-(methylimino)bis-ethanol): $CH_3N(CH_2CH_2OH)_2$; Piperazine: $HN(CH_2CH_2)_2NH$).
- In 2009, Shao and Stangeland [47] advised to focus research on the determination of atmospheric degradation paths, precise degradation yields, and degradation products' life time in the atmosphere. Another advice was to focus research on developing both acute and chronic human toxicity exposure limits for amines and associated substances.
- In 2010, a workshop on this topic was organized by IEA GHG to identify measurement campaigns and knowledge gaps to structure R&D activities.
- CESAR, Emission measurements at Dong's pilot plant for CO_2 capture in Esbjerg: Oxidative degradation products of MEA are found in gas and liquid phase but a water wash reduces the amount of emitted MEA and formaldehyde
- Mitsubishi Heavy industries, MHI Amine emission control technology: Pilot plants test results indicate that degraded amine was less than 0.2 ppm as vapor. R&D topics actively pursued are the evaluation of the environmental effects, photogenic reaction in the air of released amine and the effect of nitrosamines into aquatic environment.
- Fluor, Econamine FG+ Process, recent advances in emissions control: A new scrubbing system has been developed by Fluor with reduced solvent emissions of 0.1 to 0.2 ppm in the vent. This process will be tested in a demonstration plant in Germany in 2011.
- Aker Clean Carbon, emissions measurements and analysis from Mobile Carbon Capture Test facility: Results from various measurement campaigns indicate that sampling and analytical methods will give different results and are challenging due to the low concentrations of the compounds. Given the uncertainties, more campaigns and results are needed in order to provide rigorous conclusions on emission levels.

alkanolamine-based solvents may result in the emission of VOC and NH_3 due to the degradation of the solvent [28,32,33]. Korre et al. [34] report that NH_3 emission from using the MHI KS-1 solvent is expected to be higher than from using MEA or potassium carbonate.[3] Contrarily, IEA GHG [35] reports lower values for NH_3 emissions for the MHI KS-1 process compared to Fluor's process based on MEA.

Also, the direct emission of MEA has been reported. The exact quantity of this 'MEA slip' (estimates range between 1 and 4 ppmv) and possible effects on the environment, including human safety, are not fully known, see Box 1. By contrast, the exact composition of solvents with additives is classified, as this is part of competition sensitive information. Data on exact emissions of reaction products from these additives or emissions of the additives themselves are also not known to be publicly available. In addition, solvent additives (e.g. corrosion inhibitors) may result in trace emissions of heavy metals [36].

For the K_2CO_3 sorbent the slip to the atmosphere is considered negligible. Furthermore, this substance is considered less toxic to the environment [37,38]. K_2CO_3 may however require the addition of promoters to increase the reaction rate. Some promoters, like arsenic trioxide and piperazine, are known to be toxic [38].

Allaie and Jaspers [39] claim that the use of amino salts does not result in ammonia formation, losses due to evaporation and virtually nil emissions of the solvent. Furthermore, amino acids are according to Hetland and Christensen [40] biodegradable.

The emissions of gas fired power plants equipped with post-combustion CO_2 capture are also affected. NO_x emissions[4] are expected to be reduced per primary energy input but are expected to increase per kWh. NH_3 emissions increase for both, due to the emission of solvent or its degradation products, see Fig. 2. The higher oxygen concentration in the flue gas from natural gas combustion possibly results in higher oxidative degradation of solvents. MEA is for instance susceptible to this type of degradation [43]. However, as other impurities such as SO_2 and PM are virtually not present in the flue gas, overall degradation is considerably lower compared to coal fired power plants.

[3] In this case piperazine, an amine, is added to the potassium carbonate sorbent as an activator to increase reaction rate.

[4] The main fraction of NO_x is formed by NO which is expected to be unaffected by the CO_2 capture process. NO_2 fraction of NO_x, which is typically about 5–10%, may react with the solvent resulting in a reduction of NO_x emission per $MJ_{primary}$. However, also not all of the NO_2 is expected to react, i.e. only 25% [41,42].

Table 3
Raw water usage[a] in conversion technologies equipped with various CO_2 capture technologies.

Conversion technology/CO_2 capture technology	Source	Water usage w/o capture (L kWh^{-1})	Water usage with capture (L kWh^{-1})	Annual increase[b] million (m^3 yr^{-1})	Relative increase in water use (%)	Relative increase in primary energy use (%)
IGCC/pre-combustion	[60][c]	2.57–3.12				
	[61][d]	0.6	0.9	1.97	50%	16%
	[59][e]	1.35–1.42	1.81–2.00	3.02–3.81	32–48%	18–28%
NGCC/post-combustion	[60][c]	1.88				
	[59][e]	1.02	1.84	5.39	81%	16%
PC subcritical/post-combustion	[60][c]	4.43				
	[61][d]	3.1				
	[59][e]	2.56	5.04	16.30	96%	48%
PC supercritical/post-combustion	[60][c]	3.94				
	[61][d]	3.1	4.1	6.57	32%	31%
	[59][e]	2.25	4.34	13.74	93%	44%
Oxyfuel combustion with CO_2 removal	[62][f]	–	2.97–3.01	4.84–5.13[g]	33–35%[g]	39–41%[g]

[a] Raw water usage is defined as the total internal water consumption minus internal recycling.
[b] This is calculated as the difference between a 1 GWe power plant with capture and a 1 GWe power plant without capture, both with a capacity factor of 75% (6575 full load hours yr^{-1}).
[c] Based on power plants equipped with evaporative cooling towers. Ranges for IGCC represent various gasifier technologies (GE, Shell and E-Gas).
[d] Reflect life cycle emissions. Not specified whether figures are based on power plants with evaporative cooling tower(s) or once through cooling configuration.
[e] Based on power plants equipped with evaporative cooling towers. Ranges represent various gasifier technologies: GE, Shell and E-Gas. For cases from this source it is reported that 71–99% of water use is due to cooling tower water make-up.
[f] Based on power plants equipped with evaporative cooling towers. Ranges represent variations in the purity of the oxygen supply for combustion.
[g] Compared to supercritical PC power plant without CO_2 capture as presented in [62].

3.2.2. Pre-combustion

In coal and biomass fired pre-combustion concepts using solvents, no solvent emission to the air is expected during normal operation as any slip of the solvent would be combusted in the gas turbine or end up in the CO_2 stream. NO_x emissions are still an area of research for the turbine manufacturers of the IGCC with pre-combustion CO_2 capture. The hydrogen rich fuel may increase NO_x emissions from the gas turbine section due to the different combustion characteristics of hydrogen compared to natural or syngas. Therefore, in Fig. 1, an additional flue gas cleaning step, a $DeNO_x$ installation, is included after the gas turbine section. This can be installed if NO_x emissions are required to be lower than can be achieved by turbine development alone. A possible trade-off is that this results in NH_3 emissions from the $DeNO_x$ installation.

Co-sequestration of H_2S is technically possible. Acid gas co-injection is common in, for instance, Canada [48]. In essence, the CO_2 capture unit is an acid gas removal unit. Such units are already applied in IGCC configurations for the removal of H_2S. The removal of H_2S from the syngas may be enhanced by adding CO_2 removal. Some H_2S may also end up in the CO_2 stream.

3.2.3. Oxyfuel combustion

The main effect of oxyfuel combustion is the change in the composition of the flue gas. For we refer to [22,49–51]. In Fig. 1, it is shown that flue gas recycling (FGR[5]) in the oxyfuel concept is needed to reduce the temperature in the combustion step. The cleaning of flue gas in coal fired oxyfuel concept has the additional purpose of limiting fouling, erosion and corrosion further down the chain. Removal of particulate matter, NO_x and SO_x may therefore be necessary.

FGR also leads to an additional reduction of NO_x formation during the combustion process. Typically less (24–40%) NO_x is formed in the boiler as NO_x is now virtually limited to fuel bound NO_x formation and some possible formation due to air in-leakage. For gas fired concepts NO_x is virtually eliminated as fuel bound NO_x is virtually nil [52].

SO_x composition in the flue gas changes for the coal fired power plants, i.e. higher concentrations of SO_3 and higher retention of sulphur in ashes are reported. This enables the use of other or adapted desulphurization technologies; none of which has been demonstrated at commercial scale, however. According to [53,54] a high removal of SO_2 (64 and ~100%) and NO_x (48–90%) is possible in the CO_2 conditioning and compression section. A detailed review of the impacts of sulphur impurities on the coal fired oxyfuel cycle by Stanger and Wall [51] yielded the insights that the choice for proposed desulphurization will strongly depend on the regulations that are to be set for transport and storage of CO_2, and perhaps co-storage of sulphur compounds.

The estimates for NO_x emissions from oxyfuel combustion of solid fuels vary considerably, mainly due to the various CO_2 purification configurations proposed.

More insight into the effect on emissions comes from the results of a coal fired demonstration project in Germany [55]. There, possible configurations for flue gas cleaning are predominantly based on (adapted) conventional flue gas cleaning technologies. The additions compared to a conventional configuration consisting of an SCR, ESP and FGD, are a flue gas cooler (FGC) and CO_2 compression & purification process. The FGC is aimed to reduce the temperature, acidic substances (SO_2 between 93 and 97%, SO_3 between 58 and 78%), water content (>85%) and particulates (>90%) in the flue gas prior to compression. In the following compression & purification step, additionally NO_x, SO_x, HCl, water and heavy metals are removed as condensate from the compressors and with the use of an activated carbon filter and an adsorber [56–58]. Overall, a deep reduction of SO_2 and NO_x emissions is expected to be possible with oxyfuel combustion, although R&D is required to better understand the behavior of these substances in the CO_2 compression & purification process. This includes attaining better understanding of the thermodynamic properties of mixtures of SO_2, H_2O and supercritical CO_2; and insights into the effect of SO_3 formation on heat exchanger operation and material selection [51].

3.3. Water

3.3.1. Water consumption

Water consumption increases due to the energy penalty and the additional water demand by the CO_2 capture system.

Table 3 shows an overview of several studies reporting the raw water use per kWh. The relative increase in water use is in most studies higher than the relative increase in primary energy. This is

[5] FGR is applied to control the combustion temperature, as this is limited by materials currently applied.

Table 4
Waste streams and by products of coal fired power plants with and without CO_2 capture.

Waste/by-product	Technology	Source	W/o capture (g kWh^{-1})	With capture (g kWh^{-1})	Annual increase[a] (kt yr^{-1})	Relative increase (%)
Solvent waste	PC post-combustion	[67]	–	2.63 (Fluor)	17.29	–
		[67]		0.26 (MHI KS-1)	1.71	
		[19]		2.1 (MEA)	13.81	
	IGCC pre-combustion	[67]	0.01	0.02	0.07	100%
Gypsum	PC post-combustion	[19]	9.08	11.91	18.61	31%
		[35]	15.23	21.15	38.92	39%
		[67]	13.8	18.8–19.1	32.87–125.57	36%/38%
		[59]	53.6[b]	77[b]	153.84	44%
		[59]	47.8[c]	70.3[c]	147.93	47%
Sulphur'	IGCC pre-combustion	[67]	2.78[d]	3.48[d]	4.60	25%
		[67]	3.16[e]	3.81[e]	4.27	21%
		[59]	8.7[e]	10.4[e]	11.18	20%
		[59]	8.5[f]	10[f]	9.86	18%
		[59]	8[d]	10.3[d]	15.12	29%
Bottom-/fly-ash	PC post-combustion	[67]	39.3	48.9 (Fluor)	63.12	24%
		[67]	–	48.3 (MHI KS-1)	59.17	23%
		[59]	26.5/6.6[b]	37.2/9.3[b]	70.35/17.75	40%/41%
		[59]	24.8/6.2[c]	35.4/8.9[c]	69.69/17.75	43%/44%
Slag	Oxyfuel combustion	[67]	39.3	48	57.20	22%
	IGCC pre-combustion	[67]	44.7[d]	55.8[d]	72.98	25%
		[67]	54.1[e]	65.3[e]	73.63	21%
		[59]	38[e]	45[e]	46.02	18%
		[59]	34.4[f]	42.5[f]	53.25	24%
		[59]	32.2[d]	41.4[d]	60.49	29%

[a] This is calculated as the difference between a 1 GW_e power plant with capture and a 1 GW_e power plant without capture, both with a capacity factor of 75% (6575 full load hours yr^{-1}).
[b] Subcritical steam parameters.
[c] Supercritical steam parameters.
[d] Based on Shell gasifier.
[e] Based on GE (General Electric) gasifier.
[f] Based on ConocoPhillips E-Gas gasifier.

most distinctive for the post-combustion capture cases for which the water consumption at present almost doubles as a result of the large additional cooling requirement of the CO_2 capture process. For the IGCC with pre-combustion the additional water use is due to the water requirement in the water gas shift reaction [59]. For oxyfuel combustion the limited available data suggest an increase in water usage, although the increase is less then proportional to the increase in primary energy use.

3.3.2. Emissions to water

The effect of equipping power plants with CO_2 capture on the emissions to water bodies is currently an insufficiently researched subject. Cross-media effects[6] are likely as gaseous emissions are transformed into the liquid phase [55]. Trade-offs thus will occur with the decrease in gaseous emissions as mass flows must balance. Quantification of this trade-off is not possible due to lack of publicly available data. Qualitatively some issues can however be addressed.

For example, a liquid waste stream for amine based post-combustion capture processes may come from the reclaimer section [63]. Quantities and exact compositions of this waste stream are however not known to be reported in public available literature. Increased removal efficiency in emission control technologies (e.g. FGD and pre-scrubbing) and the additional reduction in the CO_2 capture process are possible processes that likely results in a shift from air emission to water or solid stream emissions. For the post-combustion process with potassium carbonate it is possible that potassium based minerals, usually fertilizers, may be discharged with the waste water if not recovered [64].

For an IGCC without CO_2 capture (1.2 GW_e) an emission to surface water of the solvents MDEA and Sulfolane of approximately 26 t yr^{-1} is estimated [16]. This may increase due to the implementation of pre-combustion CO_2 capture.

Yan et al. [55] suggest that due to a change in the configuration of the flue gas cleaning system in coal fired oxyfuel plants contaminants may be transferred to liquid waste streams. These liquid waste streams may in turn affect overall emissions to water bodies.

3.4. Waste and by-products

The formation of waste streams and by-products in power plants firing coal and biomass is affected by the application of CO_2 capture. Waste and by-product formation is typically not an issue for natural gas fired power plants without CO_2 capture [65]. This may change when equipped with post-combustion CO_2 capture.

3.4.1. Post-combustion

Table 4 shows that in PC plants with post-combustion CO_2 capture more ash (bottom-ash and fly-ash) is formed per kWh. In the CO_2 capture unit impurities in the flue gas such as SO_x and halogen compounds react with amine-based solvents to form heat stable salts.[7] These salts reduce the CO_2 binding capacity of the solvent and are corrosive compounds that are harmful for equipment. Degradation products and other impurities are therefore separated from the solvent in a reclaimer where also solvent is recovered. Results from a study analyzing the composition of reclaimer waste implies that CO_2 capture influences the distribution of trace element emissions (Se, As, Cr, Cu, Ni, Zn and Hg) over the various waste streams from a coal fired power plant [36]. The residues from the reclaimer are to be considered as hazardous

[6] Possible shift of environmental pressure from one environmental media (water, atmosphere, soil) to the other.

[7] Heat stable salt: a salt that is not capable of being regenerated by the addition of heat.

waste [32,33,36] and can be in the order of several kilotonnes per year for a commercial scale power plant [66], see Table 4.

The most appropriate treatment of the reclaimer sludge has yet to be determined. It can possibly be treated in the wastewater treatment installation (WWT), which means that a fraction of the sludge is emitted to the surface water and the other fraction (WWT sludge) is to be disposed of. Co-firing is an option similar to that of the optional treatment of WWT sludge [68]. Re-introducing the sludge into the boiler will redistribute the elements of the sludge over other waste streams such as fly-ash, bottom-ash and gypsum and WWT effluent and sludge. As there are limits of acceptance regarding the concentration of impurities, such as mercury and other heavy metals, valorization of by-products can become a problem [69].

For coal fired PC power plants also a larger stream of solid by-product from the FGD unit, primarily gypsum, is expected due to the required improved SO_x removal efficiency and the energy penalty, see Table 4.

In the chilled ammonia concept ammonium sulphate can be a by-product that is theoretically recoverable and usable as fertilizer. This is the reaction product of SO_2 in the flue gas with the ammonia solution [31].

In the concept using potassium carbonate possible new waste or by-product streams include: nitrates, nitrites, sulphates and sulphites formed by the reaction of the sorbent with SO_2 and NO_2 [38]. If recovered, these substances can be used as fertilizers. When using sodium carbonate, it is likely that SO_2 that still remains in the flue gas reacts to sodium sulphite, -bisulphite and-sulphate, comparable with the reaction in a sodium alkali FGD scrubbing system [cf. 70]. These salts in solutions are liquid waste streams that should be treated properly.

Amino acids are reported by Allaie and Jaspers [39] to be stable and show low degradation rates which would imply that waste and by-product formation is low. It should however be noted that the results of the pilot plant test are confidential and that these results cannot be verified.

3.4.2. *Pre-combustion*

Typical waste streams and by-products from IGCC power plants are: fly-ash, bottom-ash, slag and sulphur or sulphuric acid. The amount and composition of these often marketable streams depend on the gasifier and desulphurization technologies applied and the fuel utilized [71]. Table 4 shows that sorbent waste increases with a factor 2 for the pre-combustion concept. Furthermore, the production of the marketable elemental sulphur increases per kWh. For the production of slag an increase between 18% and 29% is expected in literature, depending on the type of gasifier implemented.

3.4.3. *Oxyfuel combustion*

Davidson et al. [72] suggest that oxyfuel combustion characteristics affect the speciation and further removal of mercury from the flue gas. Oxidized mercury is more easily captured in existing flue gas control systems. Additionally captured Hg would then end up in the waste streams of flue gas control technologies such as FGD and dust control (ESP and filters). However, some flue gas control technologies may be omitted when applying oxyfuel combustion. White et al. [53,54] suggest a technology that removes SO_2 and NO_x in the form of sulphuric (H_2SO_4) and nitric acid (HNO_3), respectively. The latter substance may react with oxidized mercury (Hg^{2+}) in the flue gas producing mercuric nitrate. This is a toxic substance and should be considered a hazardous waste.

Table 5
Resource consumption by energy conversion technologies equipped with and without CO_2 capture.

Resource (process)	Technology	Source	No capture (g kWh^{-1})	Capture (g kWh^{-1})	Annual increase[a] (kt yr^{-1})	Relative Increase (%)
Sorbent make-up (CO_2 capture)	PC/post	[61]	–	3.6 MEA	23.67	–
		[19]		2.04 MEA	13.41	
		[67]		1.31 Fluor	8.61	
		[67]		0.13 MHI KS-1	0.85	
		[35]		1.31 MEA	8.61	
		[59]		0.37 Fluor (sub crit.)	2.43	–
		[59]		0.33 Fluor (super crit.)	2.17	
		[74,75]		0.18 AA[b]	1.18	
		[27]		2.16 MEA[c]	14.2	
		[28]		1.26 MEA[d]	8.28	
		[37]		0.45 K_2CO_3/PZ[e]	2.96	
	NGCC/post	[61]	–	1.33 MEA	8.74	–
		[35]		0.61 MEA	4.01	
		[59]		0.12 Fluor	0.79	
	IGCC/pre	[61]	0.02 Selexol	0.03 Selexol	0.07	50%
		[67]	0.01 Selexol	0.02 Selexol	0.07	100%
		[35]		0.005 MDEA	0.03	–
Limestone[f] (FGD)	PC/post	[55]	16.9	27.2	67.72	61%
		[19]	5.6	7.5	12.49	34%
		[67]	8.4	11.4–11.6	19.72–21.04	36%–38%
		[35]	8.4	01.6	21.04	38%
		[59]	33.6–35.9	48.2–52.7	95.99–110.45	43%–47%
Ammonia (SCR)	PC/Post	[61]	0.61	0.80	1.25	31%
		[19]	0.31	0.41	0.66	32%
	NGCC/post	[61]	0.20	0.23	0.20	15%

Note: sub crit. = subcritical steam parameters; super crit. = supercritical steam parameters indicating higher generating efficiency, i.e. a lower capture penalty.
[a] This is calculated as the difference between a 1 GW_e power plant with capture and a 1 GW_e power plant without capture, both with a capacity factor of 75% (6575 full load hours yr^{-1}).
[b] AA = Aqueous Ammonia. Based on the assumption of 0.9 kg CO_2 captured kWh. Original value 0.2 g/kg captured [74,75].
[c] Based on the assumption of 0.9 kg CO_2 captured/kWh. Reported value 2.4 g/kg captured [27].
[d] It is reported that similar ranges were found for alternative solvents 'CASTOR 1' and 'CASTOR 2'. Based on the assumption of 0.9 kg CO_2 captured/kWh. Reported value 1.4 g/kg captured [28].
[e] Piperazine promoted potassium carbonate. Based on the assumption of 0.9 kg CO_2 captured/kWh. Reported value 0.5 g/kg captured [37].
[f] Limestone use depends mainly on FGD efficiency and sulphur content of the fuel.

Table 6
Summary of risk assessments for CO_2 transport by pipeline showing the failure scenarios assessed, pressure, the pipeline diameter, section length, assumed critical CO_2 exposure threshold, the calculated maximum distance to this threshold and the distance to the individual risk contour.

Source	Failure scenario[a]	Pressure (MPa)	Pipeline diameter (cm)	Isolable Section length (km)	Exposure threshold		Distance to exposure threshold (m)	Distance to individual risk contour[b] (m)
					Concentration (ppm)	Duration (min)		
[96]	Rupture	3.5	66	5–30	50 000	1	250–750	
	Rupture	6	41	5–30	50 000	1	150–600	
[95,98]	Cumulative	13–20	61–107	30	40 000	30	1350– 1900	1900–2450
[97]	Cumulative	1.7	66	17	54 656	60		<3.5
[91][c]	Rupture	6.9	8–41		5000	10	310–1246	
	Rupture	6.9	8–41		30 000		59–89	
[94]	Rupture	15.2	36–51	8[d]	30 000	15	<1–202	
	Rupture	15.2	36–51	8	40 000	15	<1–136	
	Rupture	15.2	36-51	8	70 000	15	<1–66	
	Puncture	15.2	36–51	8	15 000	>180	265–272	
	Puncture	15.2	36–51	8	20 000	>180	168–197	
	Puncture	15.2	36–51	8	60 000	>180	44–46	
	Puncture	15.2	36–51	8	70 000	>180	35–38	
	Rupture H_2S (0.01%)	15.2	36–51	8	0.51	15	1271–6885	
	Rupture H_2S (0.01%)	15.2	36–51	8	27	15	40-593	
	Rupture H_2S (0.01%)	15.2	36–51	8	50	15	4–373	
	Rupture H_2S (0.01%)	15.2	36–51	8	0.20	>180	2136–2356	
	Rupture H_2S (0.01%)	15.2	36–51	8	0.33	>180	1628-1741	
	Rupture H_2S (0.01%)	15.2	36–51	8	17	>180	167–169	
	Rupture H_2S (0.01%)	15.2	36–51	8	31	>180	115–116	
[90]	Puncture	20.4[e]	33	30	40 000–100 000	30	70–110	
	Rupture	20.4[e]	33	30	40 000–100 000	30	170–210	
	Puncture H_2S (2%)	20.4[e]	33	30	100	30	290	
	Puncture H_2S (2%)	20.4[e]	33	30	100	30	1180	
	Puncture H_2S (2%)	20.4[e]	33	30	800	5	100	
	Puncture H_2S (2%)	20.4[e]	33	30	800	5	390	
[88]	Rupture	14	102	0.5–6.5	100 000		321–750	
[89]	Cumulative	20	102	160	2000-15 000	15	2500–7200	1500–3300
	Cumulative	10	76	50	2000-15 000	15	2000–3800	1250–2650
[112]	Puncture	1.5–3.2	76	18	SLOT DTL[f]		3–149	
	Puncture	1.5–3.2	76	18	SLOD DTL[g]		3–107	
	Rupture	1.5–3.2	76	18	SLOT DTL[f]		100–160	
	Rupture	1.5–3.2	76	18	SLOD DTL[g]		71–107	
	Cumulative	1.5–3.2	76	18	SLOT DTL[f]		3–160	0–20[h]
	Cumulative	1.5–3.2	76	18	SLOD DTL[g]		3–107	0[h]
[99][i]	Cumulative	4–20	41	20	27 000	10	194–800	0–204
	Cumulative	4–20	41	20	55 000	10	0–524	

[a] 'Cumulative' encompasses multiple scenarios, i.e. both rupture and puncture scenario.
[b] The individual risk contour here indicates the probability of adverse impact (in 1.0×10^{-6} yr^{-1} km^{-1}) on an ever-present and unprotected person. Note that the probability of occurrence is taken into account when determining the individual risk contour contrary to when determining the distance to the exposure threshold. The adverse impact is considered to be 'fatality' by [95,98] (70 000 ppm for several minutes) and [97] (assumed 1% fatality at 100 mg/m^3 for 60 min); 'non-fatal' is the impact assumed in [89] (at 15 000 ppm).
[c] In [91] also significant shorter distances are calculated for receiving the shown concentration levels at 1.5 m above ground level additional distances received at ground level shown here.
[d] One of the pipelines in this study has a length of 0.8 km which equals in that case the isolable section length.
[e] Maximum operating pressure of the pipeline.
[f] Is determined as Specified Level of Toxicity Dangerous Toxic Load which equals 1% mortality and is set at $1.5 \times 10^{40} = (ppm^8 \times min)$.
[g] Is determined as Significant Likelihood of Death Dangerous Toxic Load which equals 50% mortality and is set at $1.5 \times 10^{41} = (ppm^8 \times min)$.
[h] Indicating the distance to the pipeline at which the chance of receiving the Dangerous Toxic Load equals 1×10^{-6} yr^{-1}.
[i] In [99], a sensitivity analysis was performed varying the type of release (instantaneous, horizontal and vertical jet, dry-ice bank sublimation), the failure rate (0.7×10^{-4}–6.1×10^{-4} km^{-1} yr^{-1}) and dose-response (probit) function.

Also, the ash formation per kWh increases (see Table 4) and the composition of fly and bottom-ash may change as a consequence of oxyfuel firing [73]. A significant change in composition could pose problems for its qualification as usable by-product. Yan et al. [55] also state that due to oxyfuel combustion more gaseous contaminants will be transferred to liquid, solid waste or by-product streams. Quantitative data are however not available.

3.5. Resource consumption

For NGCC the main resources used, besides fuel during operation, are ammonia and catalyst make-up for the removal of NO_x in an SCR [12,13]. Furthermore, chemicals are used for the conditioning of the cooling water and production of demineralised water for the steam cycle. Substances typically used in the normal operation of a PC power plant are: limestone, ammonia, sodium hypochlorite, lubricants, caustic soda, hydrochloric acid and sulphuric acid.

For the post-combustion capture concepts, the consumption per kWh of most of the above mentioned substances will increase with the energy penalty, see Table 5. The exception may hold for ammonia and limestone if the efficiency of the SCR and FGD section is required to improve, e.g. in the case of a retrofit. Amine based capture technologies require deep removal of both NO_x and SO_x to minimize solvent loss, the latter being the dominant target substance. Supap et al. [43] report that higher MEA concentrations in the solvent, next to O_2 and SO_2, also increase the degradation rate. High CO_2 concentrations were found to decrease the degradation rate. For gas fired concepts the degradation rate and solvent consumption are expected to be lower.

Caustic soda may be used to remove acid components in a scrubber prior to CO_2 removal. In addition, NaOH may be used too in the CO_2 capture process to reclaim part of the solvent that reacted with impurities [19,41]. Both lead to an increase in its consumption compared to a power plant without CO_2 capture.

The consumption of solvent in the capture process is an important driver for solvent development as solvent loss deteriorates operational economics and has environmental consequences.

Table 5 clearly shows that the consumption of the sorbent varies per type of sorbent. Typically, the consumption of MEA is higher compared to its alternatives. Moreover, the consumption of sorbents used in IGCC with or without pre-combustion concepts can considered to be very low, although an increase is expected when CO_2 capture is applied.

In the coal fired oxyfuel combustion concepts ammonia and limestone are used. Quantitative details on their consumption in adapted flue gas cleaning configurations are not known to be publicly available.

3.6. *Findings CO_2 capture at power plants*

We found that depending on the applied CO_2 capture technology, trade-offs and synergies can be expected for key atmospheric emissions. An increase in water consumption ranging between 32% and 93% and an increase in waste and by-product creation with tens of kilotonnes is expected for a 1 GW_e power plant, but exact flows and composition are uncertain. Further, we found that there is considerable uncertainty on how the environmental fate of emissions may shift when equipping power plants with CO_2 capture. Information on cross-media effects when capturing CO_2 is underexposed at present and not quantified. We recommend that environmental monitoring programmes for demonstration plants should help to fill this knowledge gap on cross-media effects.

An important consideration in the EIA for power plants is that its design should be benchmarked against the Best Available Technology (BAT) described in the BAT Reference documents[8] (BREF) issued under the IPPC Directive for energy efficiency, pollution control and cooling water discharge, see [65,76,77]. Benchmarking is not yet possible as neither a BAT for CO_2 capture options is established nor is CO_2 capture considered BAT for large combustion plants. In fact, no elaboration on the environmental impacts of CO_2 capture is included.

This also includes the absence of emission performance standards for key (solid, atmospheric and liquid) emissions that take into account the efficiency penalty due to capture. Human safety norms do exist for some of the additional emitted substances, like amines and their degradation products. However, in general, the development of exposure limits for these type of substances has been identified as an important knowledge gap by Shao and Stangeland [47].

The knowledge base, from which a BREF is distilled, still has to be created for CO_2 capture. The compilation of test results from the various (pilot and demo) CO_2 capture facilities worldwide can be a valuable source of information to gradually expand and improve the BREF for Large Combustion Plants regarding capture options and its relation with other emission reduction techniques.

In the BREF for economic and cross-media effects a truncated version of the Life Cycle Analysis approach is proposed to determine the BAT for an individual activity taking into account multiple environmental themes.[9] The approach is truncated in the sense that it, in principle, limits the system boundaries of the study to the proposed activity and its possible alternatives and thus does not include up- and downstream effects of the process [78]. That BREF and our review are not aimed at identifying life cycle effects of implementing CO_2 capture options, but this should not be neglected when reviewing the environmental performance of complete CCS chains, from cradle to grave. Recent studies namely indicate that some direct emissions, like SO_x, may decrease due to CO_2 capture; but that additional life cycle emissions by up- and downstream process may result in a deterioration of the overall environmental performance of the CCS chain compared to a power plant without CCS, see for instance [17–19,35,61,79–87].

4. Transport of CO_2 by pipelines

In the international arena, primarily in the United States, there is significant experience with transporting large quantities (i.e. several Mt per pipeline) of CO_2 by pipelines at high pressure, primarily for EOR projects. Several thousands kilometers of pipeline are being operated for this purpose. High-pressure transport is required as economics are not favorable for transporting large amounts of CO_2 over considerable distances in the gas phase. The CO_2 is therefore transported in the dense liquid or supercritical phase (i.e. above 31 °C and 7.38 MPa). The modeling of the dispersion of high-pressure CO_2 releases in risk assessments was in the introduction of this article already identified as a knowledge gap. In the following section, we will focus the assessment on the external safety of high-pressure CO_2 pipelines as it is indicated that this is one of the most important issues in the environmental assessment of CO_2 transport pipelines.

Various quantitative risk assessments (QRA) have been performed for CO_2 pipelines, see e.g [88–98]. A summary of the results of these studies is presented in Table 6. A review of these studies was performed by Koornneef et al. [99] yielding insight in the knowledge gaps and their impacts on the assessment of external safety of CO_2 transport by pipeline. Also, Eldevik et al. [100] and UK's Health and Safety Executive [101] provide insight into the current knowledge base on the safety of high-pressure CO_2 pipelines. The main conclusions of these studies are summarized below.

4.1. *Failure rates for CO_2 pipelines*

Failure rates used in QRAs range between 0.7 and 6.1×10^{-4} yr^{-1} km^{-1} and are often based on experience with natural gas pipelines. A failure is predominantly caused by third party interference, corrosion, construction or material defects (e.g. welds), ground movement or operator errors [98,102]. Terrorism is presumably an underexplored factor in risk assessments for CO_2 pipelines. This factor should not be ignored although we presume that CO_2 pipelines are less likely targeted than hydrocarbon pipelines.

Currently, empirical data on the operation of CO_2 pipelines is not sufficient to determine the probability of failure of a pipeline section with the same accuracy as for natural gas pipelines. Furthermore, the presence of impurities and water influences the corrosion rate of CO_2 pipelines. Depending on the CO_2 capture process, the process flow may constitute toxic and corrosive impurities. Expected impurities are H_2O, SO_x, NO_x, N_2, O_2, H_2S, CO and H_2. Current models seem not to be appropriate to accurately estimate corrosion rates when taking these impurities into account and with it fall short in providing quantitative information to determine the possibility of failure due to internal corrosion, see also [100]. The presence of free water is the dominating factor here and should be minimized to restrain corrosion to a high extent [103]. The presence of impurities may also influence

[8] The BREFs for Large Combustion Plants (LCP) [65] for Industrial Cooling Systems and for Monitoring are applicable.

[9] It includes 7 environmental themes: human toxicity, global warming, aquatic toxicity, acidification, eutrophication, ozone depletion and photochemical ozone creation potential.

Table 7
General description of EIA procedures for activities in the geosphere reviewed this study.

Project short name	Description	Source
Analogous projects		
UGS Norg (Netherlands)	Underground gas storage project in the Netherlands in an empty gas field at a depth of ~2700 m.	[113,114]
EOR Schoonebeek (Netherlands)	Enhanced oil recovery project using steam injection including the injection of produced water in nearby empty hydrocarbon reservoirs and aquifer at a depth of 1500 and 3000 m.	[115]
Gasselterenijveen (Netherlands)	Gas production project including the injection of produced water in nearby empty hydrocarbon reservoirs at a depth of 800 m and >3000 m.	[116]
CO_2 storage projects		
Frio, Texas (United States)	CO_2 storage pilot in saline aquifer at a depth of about 1500 m.	[117]
Gorgon Gas development (Australia)	Gas production project including the removal of CO_2 from the natural gas and injection into an aquifer at a depth of 2000 m.	[118,119]
AMESCO (Netherlands)	Generic environmental impact assessment for CO_2 storage in Dutch onshore gas fields.	[120]
CO_2 storage Barendrecht (Netherlands)	CO_2 storage in depleted onshore natural gas reservoirs at a depth of 1700 m (phase 1) and 2500 m (phase 2).	[8,108,121]
FutureGen (United States)	Integrated CO_2 capture, transport and storage project to be located in the United States (four storage sites pre-selected with reservoirs at a depth of 0.6–2.6 km).	[122]

thermodynamics (i.e. the phase) of the CO_2 flow resulting in energy losses [100,102–105]. This influence on thermodynamic properties is also important in case of a sudden release or leakage from the pipeline.

4.2. Release and dispersion of CO_2

The maximum CO_2 release rate from a failing pipeline is estimated in [99] to range between 0.001 and 22 t s^{-1} depending mainly on the diameter of the pipeline and the size of the puncture. Other studies report somewhat lower rates of 8.5 t s^{-1} [96] and 15 t s^{-1} [95].

Impurities may affect the phase, temperature and pressure during the accidental release and dispersion the CO_2. Another important aspect is that expanding CO_2 may involve phase changes that result in (dry) ice formation in the surrounding of the pipeline, see also [106]. This in turn affects the release and dispersion of the CO_2. Eventually, this has effect on the concentration of CO_2 and impurities in the surrounding of a failing pipeline. These effects are currently not rigorously addressed in existing models. Field-testing and (further) validation of release and dispersion models is thus necessary for a more accurate assessment of the external safety of CO_2 pipelines. Field scale CO_2 release and dispersion experiments have been undertaken by BP and Shell in the recent years, respectively in 2006 and 2010. In the joint industry project CO2PIPETRANS these data are used to validate release and dispersion models. Experiments are also planned within the Dutch CATO2 programme.

The models that are being used to estimate the dispersion of CO_2 can typically be divided into Gaussian/dense-gas models and CFD (computational fluid dynamics) models. The first group of models is more widespread and has typically shorter computation times. It also requires a smaller data set to perform the calculations. Recent studies do however suggest that CFD models can more accurately assess the dispersion of CO_2 and indicate that Gaussian/dense-gas models tend to over-estimate (up to one order of magnitude) concentrations of dispersing CO_2 [107].

Another aspect is that release characteristics, such as the direction (vertical or horizontal) and momentum (impinged or unimpinged jet or instantaneous release), have a significant impact on the outcomes of a QRA. Currently, no uniform assessment methodology prescribes how to cope with assumptions on the direction and momentum of the release.

4.3. Possible impact of accidental release

The estimation of the impact of an accidental release on human safety is highly determined by the methodology used. Some studies assume a concentration threshold for CO_2 and impurities, while other methodologies include a dose-response function.

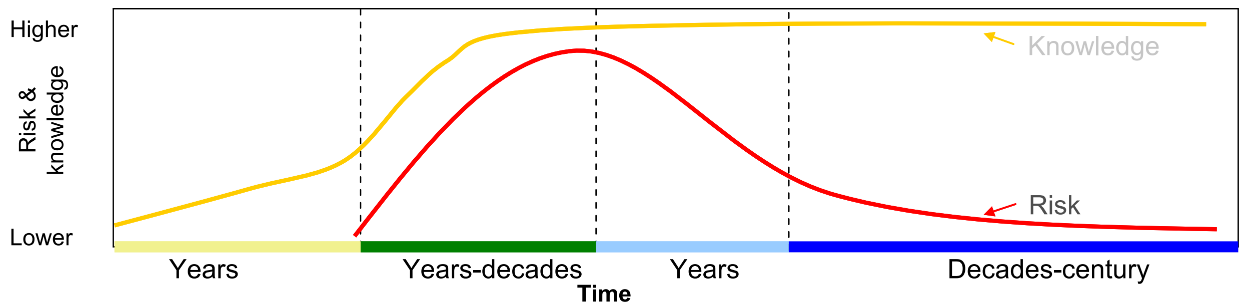
Table 6 shows that the assumed type of threshold has large influence on the outcome of the RA in literature. Consequently, effect distances to these thresholds vary orders of magnitude. Thresholds are often incommensurable as they vary in three main characteristics of the threshold: the concentration, the duration and the effect. The level of the effect belonging to the various thresholds in the reviewed literature varies between 'adverse effect on the environment' and 'fatality'. In the dose-response function, concentration and duration are used to estimate the fraction of fatally injured people. Currently, a variety of concentration thresholds is used worldwide and no formal dose-response function is adopted yet [95,99,108]. Work has been done by ter Burg and Bos [109] to establish such a dose-response (probit) function.[10] They however conclude that more scientific research is needed aimed at understanding the complexity of the relationship between CO_2 concentration, duration of the exposure and the resulting fatality in humans. A probit function could not be proposed in absence of this understanding. Instead, ter Burg and Bos [109] propose to use conservative concentration thresholds[11] as long as a reliable probit function is absent. Reviewing Table 6 also yields the observation that impurities like H_2S may dominate the risk of CO_2 pipelines.

4.4. Findings CO_2 transport by pipeline

Overall, these limitations of current risk assessment methodologies and models limit the possibility to compare outcomes of QRAs case by case and with existing industrial activities. Difficulties

[10] The probit function has the form: $Pr = a + b \times \ln(C^n \times t)$. Pr is a representation of the response fraction, e.g. percentage of people fatally injured. In this equation a, b and n are substance specific constants describing the lethality related to a dose of a toxic substance, explosion or heat, C is the concentration (in kg/m^3) and t is the exposure time (in s) [110].

[11] ter Burg and Bos [109] propose to use the following thresholds: no deaths are expected at CO_2 concentrations of up to 50,000–100,000 ppm, serious effects and possible mortality may start to occur at about 100,000–150,000 and a high level of mortality may occur at about 200,000–250,000 ppm.



Phase	Preparation and construction	Operation (injection)	Dismantling and abandonment	Post closure
Detection/ Monitoring	-Site screening and ranking; -Geological characterization: capacity, injectivity, containment; -Seismicity baseline; -Baseline monitoring biosphere.	-High frequency and high resolution monitoring of subsurface (incl. well): injection characteristics (pressure, temperature composition, rate) and fate of CO_2 ; -Seismicity; -Monitoring biosphere.	-Targeted monitoring of geosphere and biosphere.	Decreasing occasional monitoring of geosphere and biosphere. Less monitoring tools available due to closure of well.
Modeling	-Long/short term simulation: hydrodynamics, geomechanics and geochemistry; -Risk assessment.	Validate/update models and re-evaluate: -Injection plan; -Monitoring plan; -Risk assessment and mitigation/remediation plan.	Validate/update models and re-evaluate: -Monitoring plan; -Risk assessment and mitigation /remediation plan.	Validate/update models and re-evaluate long term : -Monitoring plan; -Risk assessment and mitigation/remediation plan.
Dominating trapping mechanism		Primary mechanisms (structural, stratigraphic and hydrodynamic trapping).	Increasingly secondary mechanisms (residual, solubility and mineral trapping).	

Fig. 3. Indicative graphical representation of the typical four phases of a CO_2 injection project with its relation to monitoring and modeling efforts, dominating trapping mechanisms and the development of knowledge (inverse of uncertainty) and risk over time. Based on [123–125]. Note that the 'knowledge curve' for aquifers in general starts below that of oil and gas reservoirs.

also persist in drawing risk contours[12] for CO_2 pipelines, see also Table 6.

It is recommended that efforts should be undertaken to improve the accuracy of a QRA for CO_2 pipelines. These efforts should be focused on 1) the validation of release and dispersion models for high-pressure CO_2 including impurities and 2) the development of a universal dose-response model for CO_2.

Best practice guidelines for the design and operation of CO_2 pipelines have been developed recently, providing first guidance steps [111]. We recommend further development and implementation of detailed guidelines for assessing the risk of (high-pressure) CO_2 pipelines. These should include a definition of the type of failures that should be assessed, the methodological choices to be made, uniform exposure thresholds and dose-response model, and safety distances for CO_2 pipelines.

5. Activities in the geosphere – storage of CO_2

Analogous activities to CO_2 storage in the underground are underground gas storage (UGS), acid gas injection and hydrocarbon production projects like EOR. There is extensive experience with these activities worldwide and also with concluding EIA procedures for such activities.

These activities can be used as a point of reference for the EIA procedure for CO_2 storage projects. In addition to concluded and ongoing EIA procedures for CO_2 storage projects, we have studied analogous activities like storage of natural gas in gas fields and in salt caverns, and EOR projects. The EIA procedures assessed in more detail in our study are presented in Table 7. Worldwide there are more CO_2 storage projects[13] being operated or planned than presented in this table. For these projects either no EIA procedures have been concluded or the accessibility of the related documents was limited, hence they were not reviewed in detail.

The storage of CO_2 in the deep underground encompasses various options: aquifers, (nearly) depleted hydrocarbon reservoirs, underground (unminable) coal layers and salt caverns. The focus in our study is on the first two options as these have the highest estimated storage potential [42].

CO_2 storage in these geological formations encompasses the injection of CO_2 into porous rocks that may hold or have held fluids like gas, oil and brine. Important considerations for choosing a suitable single formation, or geological formations at all for that matter, are the injectivity, capacity and containment [123,124]. The first requires that the permeability of the rock is sufficiently high to enable that the CO_2 can be injected. The second, capacity, is determined by the available space in the rock which is mainly dependent on the dimensions of the formation, the porosity of the rock and the density[14] of the CO_2. Finally, the containment of CO_2

[12] An individual risk contour depict the probability per year on a topographical map that an unprotected ever-present person dies at a certain distance from the pipeline due to the accidental release of the CO_2.

[13] Currently (2010) operating CO_2 storage projects are: Sleipner and Snohvit, Norway; Weyburn, Canada; In-Salah, Algeria; K-12B, Netherlands; Ketzin, Germany; Otway, Australia.

[14] The density of CO_2 increases with increasing depth, i.e. increasing pressure. Therefore, geological storage is considered in formations from a depth of 800 m as CO_2 is, in general, in the supercritical phase from that depth.

should be safeguarded to inhibit the CO_2 from moving outside the target formation. Several short and long-term trapping mechanisms prevent the CO_2 from leaking, see Fig. 3.

One of the most important leakage barriers is the presence of an impermeable rock layer, or caprock, which seals the formation. This feature makes formations that held fluids such as natural gas and oil for geological time attractive for CO_2 storage. This sealing capacity is however not proven for all of the aquifers. These formations are also less studied compared to hydrocarbon formations rendering more uncertainty regarding sealing capacity (containment), injectivity and storage capacity [42].

In this section, we will not address all environmental consequences of CO_2 storage, but only focus on 'new' possible environmental consequences that are most likely to be assessed in an EIA. Furthermore, the focus is on the environmental indicators and tools that are used to determine and communicate these consequences. We will distinguish between several environmental compartments: the underground (including target storage reservoir and wells), the overburden and the biosphere (including atmosphere, groundwater, vadose zone,[15] and surface water).

If we divide the storage activity simply into above ground activity and underground activity, the new environmental concerns are related to the latter. The above ground activity including construction, operation and dismantling of infrastructure can be considered current practice. A clear difference between the EIA procedures for CO_2 storage projects and those for analogous activities is the extensive additional attention to the performance of the geological reservoir. More specific, the safe and long-term storage of CO_2 is an important new issue in these assessments compared to current activities in the geosphere. In the following section we will therefore focus on the risks of CO_2 storage, as this is one of the most important remaining issues in the environmental assessment of CO_2 storage.

We will assess the tools and indicators that are used to assess the Health, Safety and Environmental (HSE) consequences of CO_2 storage. Also, an overview will be presented of tools that are available to monitor the performance and possible effects of CO_2 storage. Finally, we will assess the measures that can be applied to mitigate and remediate HSE consequences in the case of a failure in the containment of CO_2.

5.1. Leakage scenarios

Several scenarios conceivable may result in the leakage of CO_2 from the target reservoir. Often investigated scenarios are: leakage through existing or induced faults and fractures, leakage along a spill point, caprock failure or permeability increase and leakage along a well and wellhead failure.

Injecting CO_2 in the targeted reservoirs will result in pressure changes in the reservoir which may re-activate faults and fractures. These may result in seismic events. Another consequence may be the creation of preference pathways for CO_2 migration from the reservoir into the overburden which eventually could result in leakage of CO_2 into the biosphere [119,126]. In the Gorgon project therefore a mitigating action has been proposed to limit pressure build-up. This includes the production of water from the reservoir to lower the pressure. This water is planned to be re-injected into another pressure depleted reservoir (as proposed), discharged directly or to be treated and then the effluent is discharged in surface water bodies. This risk mitigating activity at least requires the drilling, operation and abandonment of additional wells, with attached environmental consequences. More detailed information on the environmental interventions and impacts associated with produced water from the analogous oil and gas production projects can be found elsewhere, e.g [127–130].

Injection of CO_2 in the reservoir may also result in a pressure build-up beyond the boundaries of the CO_2 plume [126,131]. In the case of a depleted oil or gas field the pressure will increase towards the original pressure of the reservoir. In case of an aquifer, the pressure will increase above the original pressure in the reservoir. This may result in displacement of brine out of the target reservoir. This brine, including its contaminants, theoretically may come in contact with potable water layers. This indicates that with respect to this matter pressure depleted reservoirs (such as depleted oil and gas reservoirs) are in general favorable over aquifers. For aquifers, the hydrodynamic effect of injecting large volumes of CO_2 needs further scrutiny.

Leakage along a spill point, which is the lowest structural trap of a reservoir, is possible when more CO_2 is injected into the reservoir than can be hold in that reservoir [132].

Another scenario often assessed is leakage through the caprock due to a failure or due to increased permeability of this caprock. The sealing capacity of a hydrocarbon reservoir for CO_2 is in general considered to be high as the caprock has proven to hold the hydrocarbon for geological times. Such a proof is often not available for aquifers. The sealing capacity with respect to aquifers is considered less certain. There are several geochemical or geomechanical processes that may trigger a scenario that results in the failure of CO_2 containment. These are not detailed further here but more information can be found elsewhere [42,132].

Finally, a well can be a pathway for CO_2 to leak into non-targeted environmental media, including the biosphere. This may be CO_2 injection wells, but also old abandoned wells. The corrosion of materials (i.e. cement degradation) used to construct or plug the wells after abandonment is an important process that should be considered for the long time horizon of CO_2 storage. It is therefore necessary to characterize all existing wells before CO_2 injection, including: the location, type and age, in addition to the completion technique and type of materials used. The difference between hydrocarbon reservoirs and aquifers is in this respect that the number of wells drilled through aquifers is in general lower, which renders fewer pathways for leakage [132].

5.2. Effects of fluxes from the underground into the biosphere

Although several trapping mechanisms (see Fig. 3) significantly hinder CO_2 transport through geological strata, it cannot be ruled out on forehand that CO_2 does not end up in the biosphere. When this occurs, CO_2 fluxes will change the concentration of CO_2 in the soil, water bodies and/or atmosphere depending on the size of the flux. As a result, the pH of the (ground)water may decrease and with that possibly mobilizing heavy metals[16] [133–135]. The CO_2 may also act as a carrier gas, transporting other gases such as radon and H_2S into the biosphere. An extensive review of effects of elevated CO_2 concentrations in abovementioned compartments is provided in [132,136–144]. In some studies also tolerances for selected organisms to CO_2 exposure are presented [136,137].

[15] The vadose zone is the unsaturated zone between land surface and the groundwater table (saturated zone).

[16] Apps et al. [132] conclude that dissolution of pyrite and solubilization of arsenic are the most important concerns for shallow groundwater. Other elements (Ba, Pb and Zn) may in the case of high CO_2 partial pressures also approach or exceed US regulatory concentration limits. This is considered to be unlikely for Cd, and Sb. For Hg, Se and U concentrations are found to be unaffected by CO_2 intrusion.

Maul et al. [139] present a model based on observations from a natural leaking site. This model simulates the response (both toxic and fertilizing) of organisms to elevated CO_2 concentrations. However, these effects are site specific. Beaubien [145] specifically notes that the impact of CO_2 leakage (altered vegetation type and presence, microbial activity) depends on the pathways and spatial distribution of the flux.

Furthermore, environmental impacts depend on the response of local organisms to elevated CO_2 concentrations or changes in groundwater composition. For this response it is important to distinguish between long-term chronic and short-term acute exposure.

For healthy humans the effect of short-term acute exposure is in general well known. The effect of long-term chronic exposure to healthy subjects and the effect of both types of exposure for more sensitive subjects (children, elderly and the infirm) do require further investigation [144].

The effect of long-term exposure on ecosystems can be indicated as a knowledge gap [146]. In addition, it is important to understand and quantify ecosystem recovery rates after remediation of a leakage [144]. Ideally, dose-effect relationships should be known for ecosystems or target species to model the impact of CO_2 releases taking into account the level, duration and location of exposure to the CO_2.

5.3. *Safety of CO_2 storage—the assessment and results*

The conceivable scenarios for the leakage of CO_2 discussed above are typically assessed in a risk assessment. The used methodologies for CO_2 storage are mainly based on existing methodologies and tools from the hydrocarbon industry and from underground storage of nuclear waste. Here we focus on the type of indicators they provide us and how these are determined and reported in the EIA procedures.[17] When available, quantitative results of these risk assessments are presented. A concise summary of the approach and results of the reviewed risk assessments is presented in Table 8.

5.3.1. *Methodologies used in risk assessments of CO_2 storage projects*

The information presented in Table 8 yields the insight that there is currently no uniform risk assessment methodology or approach in place for the assessment of possible HSE effects due to CO_2 storage in geological formations, although there are similarities among the methodologies. One similarity is that the approach differs from RAs for 'normal' industrial activities as in the case of CO_2 storage a non-engineered system is assessed. Both the FutureGen and Barendrecht RA therefore split the assessment into an engineered and non-engineered part. The bottleneck for this latter part is however that the performance of that system cannot be assessed with high certainty on forehand.

5.3.1.1. Site characterization. Another similarity is that a site characterization is included in all reviewed studies. Accuracy of the performance assessment of the system, i.e. the assessment of the containment of CO_2, increases with increasing knowledge of the characteristics of the reservoir and its surroundings, see Fig. 3. In that figure it is shown that the knowledge curve for aquifers would in general start below that of hydrocarbon reservoirs as the latter are already extensively investigated prior and during hydrocarbon removal. The most important characteristics to be assessed are the capacity, injectivity and the containment [124]. This is followed by the identification and characterization of possible leakage pathways in the overburden.

[17] Not all reviewed risk assessments are necessarily part of an EIA procedure.

The characterization of the reservoir makes it possible to construct a reservoir model to describe the current state of the reservoir and predict possible future states resulting from CO_2 injection.

5.3.1.2. Hazard identification and failure scenarios. Next, an identification of hazards is typically performed by a panel of experts based on the characterization. A tool that is often used is a database[18] that contains several hundreds of Features, Events and Processes - or FEPs - for geological formations. Features are defined as factors that describe the current state of the reservoirs and its surroundings. Events and Processes can be described as factors that change the state of the sequestration system [147].

Expert panels are used to identify relevant FEPs and prioritize these. In this way scenarios can be developed and selected that are based on the relevant FEPs and that may be critical for the safety of CO_2 storage. In the RA for Barendrecht the FEP method has been applied in combination with the Bow-Tie method to systematically order FEPs in cause-consequence chains for the injection and post-closure phase [121].

Table 8 shows that, although there is no RA standard, studies assess comparable failure scenarios. They encompass the leakage scenarios already discussed: leakage along a well and wellhead failure, caprock failure or permeability, leakage along a spill point and leakage through existing or induced faults and fractures.

5.3.1.3. Scenario modeling. The selected scenarios can then be modeled in a (extended) reservoir model to assess the transport and fate of the CO_2 in the reservoir and other environmental compartments. However, data uncertainty is omnipresent and results in uncertain estimates for current and future states. Furthermore, although the behavior of CO_2 in reservoirs has been modeled in EOR projects and experience thus exists, these models were not developed for modeling the fate of CO_2 taking into account detailed (geochemical, geophysical and hydrodynamic) interactions with the reservoir. As a result, these models are not calibrated yet for long-term CO_2 storage [94,121,124,155]

Also, the level of detail of the applied models varies between studies. First, different reservoir models and various differentiations of existing reservoir models are being applied to cope with the special properties of CO_2 and the long-term storage of it. Second, the amount of environmental compartments and the amount of sub-models taken into account, as well as the environmental compartment that is targeted in the RA, also varies.

5.3.1.4. Alternatives to modeling – expert panels and natural analogues. A second general approach is to assess the probability and consequences of failure scenarios qualitatively with the use of an expert panel. A risk matrix with these two dimensions can be used to score the risks. Such an approach was used in the Barendrecht and Gorgon projects. A similar but quantitative approach, called RISQUE (Risk Identification and Strategy using Quantitative Evaluation), is described in [156]. This approach has been applied partially in an assessment of a CO_2 storage project in Latrobe Valley, Australia [98]. In the methodology, first a set of risk events[19] was identified. With the use of an expert panel a qualitative description of the likelihood was attributed to each event which was then converted to a quantitative

[18] A comprehensive database containing FEPs can be found at http://www.quintessa.org/consultancy/index.html?co2GeoStorage.html.

[19] The risk events identified are: leakage from exploration, production, and injection wells, leakage from permeable zone in the caprock, leakage from faults through caprock, leakage due to regional over pressurization of the reservoir, leakage due to local over pressurization of the reservoir, spill points due to limited storage capacity, leakage due to earthquake induced fractures, leakage due to failure of surface installations (pipeline, compressor and platform).

Table 8
Overview of methodologies and results of risk assessments of CO_2 storage projects, including natural analogues and proposed thresholds.

Project description	Methodology	Failure scenarios	Receiving environmental compartment	Results and indicators (L, S or I)[a]
Weyburn CO_2 monitoring & storage project (hydrocarbon) [148]	- Site characterization - FEP - Deterministic/stochastic scenario - Probabilistic scenario (CQUESTRA) - Reservoir model (ECLIPSE E-300)	- Migration from geosphere - Leakage through (abandoned) well bores	Biosphere (including 300 m subsurface)	(**L**) 0.001(mean)–0.2% CO_2ip[b] (**L**) 0.001(mean)–0.14% CO_2ip (well bore) (**L**) 16 g day^{-1} (well bore) (**L**) ~0.04–2 × 10^{-4} t yr^{-1} m^{-2} from reservoir (**S**) CO_2 concentration in layers in geosphere[c]
Safety assessment for Schweinrich structure (aquifer) [149]	- Site characterization - FEP - Simulation discrete scenarios with stochastically varied parameters in reservoir model (SIMED-II)	- Leakage through caprock - Leakage through faults	Shallow subsurface including groundwater (−80 m to 0 m)	(**L**) ~0 t yr^{-1} m^{-2} (**L**) 2.5 × 10^{-4}–6.2 × 10^{-1} t yr^{-1} m^{-2} (**S**) <4% concentration in groundwater at depth of 80 m
		- Leakage through well		(**L**) 60% CO_2ip (**L**) 15–350 t yr^{-1} m^{-2}
EIA for Barendrecht storage project (hydrocarbon) [121,150]	- Site characterization - FEP and BowTie - Reservoir model (PETREL, MoRes) - Characterization of risk (qualitative)	- Leakage through caprock - Caprock breach - Caprock seepage - Leakage along spill point	Subsurface (non-target aquifer)	(**L**) 0.03 Mt (cumulative) (**L**) ~1.5% CO_2ip[d] (**L**) <0.1% CO_2ip[d] (**L**) 0–5% CO_2ip[d]
		- Leakage through the well bore along the well casing	Subsurface/surface	(**L**) Very long cement leak >800 m: >40% CO_2ip[d]
			Subsurface/well	(**L**) Long cement leak 200–800 m: 9–40% CO_2ip[d]
			Subsurface/well	(**L**) Short cement leak <200 m: 0–9% CO_2ip[d]
			Not specified	(**L**) During operational phase: 1.9 kg–4.4 t/yr
		- Leaking well (potential leak rates through narrow cracks or conduits)	Not specified	(**L**) 0.6–1.8 t CO_2 day^{-1}
	- Release model - Atmospheric dispersion model (SafetiNL)	- Well blow out and release	Atmosphere	(**L**) 9–150 kg/s (**I**) 1 × 10^{-6} Risk contour at ~30–60 m from well
Risk Assessment for the FutureGen Project (sandstone and saline aquifer) [94]	Split in pre- and post-sequestration risk assessment for multiple sites[e,f]	- Leakage into non-target aquifers due to unknown structural or stratigraphic connections and lateral migration	Subsurface (non-target aquifers)	(**L**) 1.39 × 10^{-3}–2.36 × 10^{-1} t yr^{1} m^{-2}
	Post sequestration risk assessment: - Site characterization - Analogue database - Extrapolation - Reservoir model (STOMP) - Atmospheric dispersion model (SCREEN3)	- Leakage due to CO_2, oil, gas and undocumented wells	Atmosphere	(**S**) 60–1490 ppmv at 100 meter from well
		Leakage through: - Caprock failure - Existing and pressure induced faults	Atmosphere	(**L**) 1.39 × 10^{-3}–4.17 × 10^{-2} t yr^{-1} m^{-2} (**S**) 0.076–4.1 ppmv at 1 m from source
	Pre-sequestration risk assessment: - Release model - Atmospheric dispersion model (SLAB)	- Wellhead equipment failure	Atmosphere	(**L**) 85–510 kg s^{-1} CO_2 (**L**) 8–51 g s^{-1} H_2S (**S**) 2–8 meter to no effect level (30 000 ppmv CO_2) (**S**) 290–788 m to no effect level (0.5 ppmv H_2S)
Environmental Assessment for the Frio Formation (aquifer) [117]	- Methodology not reported in detail	- 10% of CO_2ip (max 3750 t) returned to the surface over a 1-year period		(**S**) pH of 5.28 (drop of 1.5) in overlying aquifer (**S**) 100% vapor concentration in the shallow soil (**S**) nearly 100% vapor concentration in atmosphere near leakage site
Environmental assessment for Gorgon storage project (aquifer) [118]	- Site characterization - Hazard identification - Receptor identification - Characterization of risk (qualitative)	- Failure of compressors, pipelines or wellheads - Migration along well penetrations, faults or fractures - Failure of structural seals	Surface	(**L**) 1.4 × 10^{-3}–1.4 × 10^{-1} t yr^{-1} m^{-2}
Risk assessment for Ohio River Valley CO_2 Storage Project (sandstone) [151,152]	- Site characterization - FEP - Scenario selection - Integrated geosphere model (STOMP-CO_2) - Quantification of risk[g]	- Major wellhead failure	Atmosphere (A) Buildings (Bl)	(**I**) 0.2 (A, Bl, VZ) (**I**) 0.1 (GW, SW)
		- Moderate wellhead failure, sustained leak	Groundwater (GW) Surface water (SW)	(**I**) 5 (A, Bl, VZ) (**I**) 2 (GW, SW)
		- Minor wellhead failure, leaks of joints	Vadose zone (VZ)	(**I**) 1 (A, Bl, VZ) (**I**) 0.5 (GW, SW)
		- Fractured caprock		(**I**) 3 (A, Bl, VZ, GW, SW)
		- High permeable zones in caprock		(**I**) 1 (A, Bl, VZ, SW) (**I**) 2 (GW)
		- Seismic induced caprock failure		(**I**) 0.8 (A, Bl, VZ, GW, SW)

(*continued on next page*)

Table 8 (*continued*)

Project description	Methodology	Failure scenarios	Receiving environmental compartment	Results and indicators (L, S or I)[a]
	Natural analogues[h]			
[153]	Natural flux from soil to atmosphere		Atmosphere	(**L**) 2.78×10^{-3}–2.78×10^{-2} t yr^{-1} m^{-2}
	Natural flux at volcanic active area (Mammoth Mountain)		Atmosphere	(**L**) 2.5×10^{-1}–5×10^{-1} t yr^{-1} m^{-2}
[154]	Natural flux at Solfatara, Italy		Atmosphere	(**L**) 1.10 t yr^{-1} m^{-2}
	Natural flux at Albani Hills, Italy		Atmosphere/ Groundwater	(**L**) 4.43×10^{-1} t yr^{-1} m^{-2}
	Natural flux at Mátraderecske, Hungary		Atmosphere	(**L**) 1.46×10^{-1}–7.31×10^{-2} t yr^{-1} m^{-2}
	Natural flux at Paradox Basin, UT, USA		Atmosphere	(**L**) 3.65×10^{-2} t yr^{-1} m^{-2}
	Natural flux at Latera, Italy[i]		Atmosphere	(**L**) 28 t yr^{-1} m^{-2}
	Thresholds			
[143]	Threshold based on Pb mobilization		Groundwater	(**L**) 1.7×10^{-4} kg d^{-1} 6.21×10^{-5} t yr^{-1}
	Threshold based on 3500 ppmv in air		Atmosphere	(**L**) 5.4 kg d^{-1} 1.97 t yr^{-1}

[a] L = Leakage indicator (flux or total amount of CO_2 leaked), S = Indicator for the state of the environment (e.g. CO_2 concentration), I = Impact indicators measuring the possible impact on target species.
[b] CO_2ip = CO_2 in place.
[c] Time dependent aqueous CO_2 concentration profiles beyond the boundaries of the reservoir are presented; a simple range cannot be presented here. See for details [148].
[d] Theoretical leak quantity if no barrier or time limits would apply.
[e] Pre-sequestration risk assessment encompasses the engineered system, including pipelines and wellhead failure. In this table only a selection of results of the RA for the wellhead failure is presented. In Table 6, a selection of results of the RA for pipelines is presented. Post-sequestration encompasses leakage due to storage failure.
[f] All values show the range reported for the four assessed sites/reservoirs. The additional indicator measuring the impact on target species reported in this study is not presented here, as this indicator is a risk ratio that is derived through dividing the calculated concentration by various toxicity thresholds for CO_2 (and H_2S), i.e. no dose-effect relationship is used.
[g] Risk is defined as Risk = Frequency of occurrence × Consequence × 100 000. Frequency of occurrence is defined as "events/year for well failures, and percent area of a 50 km radial zone around the injection well occupied by fault zones/high permeability features in the case of cap rock failures". Consequence is characterized Low (0.1), Moderate (0.5) and Severe (1) based on concentrations calculated for the various environmental compartments [151,152].
[h] More natural analogues are reported in [94].
[i] Flux estimate comes from [94].

probability (probability/1000 yr). Leakage rates per event and per year, as well as the total duration of the leakage, were quantified by the expert panel. Then, a risk quotient was defined as the product of likelihood and consequence. The outcomes were compared with a pre-determined maximum acceptable risk quotient.

A third RA methodology is to match the target storage formation with natural analogue sites where CO_2 is contained in the underground or where leaks into the biosphere occur. Characteristics of candidate site are first matched with those of natural sites. The release characteristics (pathways, magnitude, probability and duration) of those 'best fit' analogues are then extrapolated to the candidate site. Thus, based on similar geological characteristics possible leakage fluxes are estimated. This approach has been applied in the FutureGen study.

5.3.1.5. Quantification of risks. Theoretically, a quantitative risk assessment can be performed for a CO_2 storage activity. Based on results from geosphere modeling and quantitative estimates for the probability of each scenario, a quantitative score for the risk (i.e. a product of probability and consequence) of a storage failure can be presented. The additional step performed here is that the concentrations of CO_2 or pH values in environmental compartments are translated into indicators to measure possible impacts. A simple approach based on a simple dose-effect relationship has been suggested and applied by Saripalli et al. [151,152], see Table 8.

Regarding the environmental compartments, it can be seen that only the RA for the FutureGen and Ohio River site include an atmospheric dispersion model to assess the concentration of CO_2 in the atmosphere. In the other RAs atmospheric dispersion is not included. Exposure of target species (e.g. humans) to CO_2 is then difficult to determine and quantify. We deem the inclusion of atmospheric dispersion models in RAs for geological storage desirable when failure scenarios suggest possible leakages to the atmosphere.

5.3.1.6. Post closure phase uncertainties. Fig. 3 shows that for CO_2 injection projects an additional phase is included compared to typical analogous projects, the post-closure phase. This brings forth additional uncertainties as current practice in the oil and gas production and injection sector is not aimed at assessing the long-term performance of the underground reservoir. Typical challenges mentioned by Cooper [124] related to this extended time horizon are: data limitations, dynamic modeling of CO_2, long-term subsurface interactions and caprock characterization.

Not shown in Table 8 is the timeframe that is taken into consideration when assessing the risks. For these studies the mentioned timeframe ranges between 100 and 10,000 years. This suggests that if results from these studies are to be compared, this difference may have an effect on the results. That is, the cumulative probability of failure will increase when longer time horizons are considered. However, annual failure probabilities will likely decrease with time as secondary trapping mechanisms like mineralization and dissolution will play a more important role, see Fig. 3.

5.3.1.7. Estimation of failure frequencies. The estimation of failure rates (quantitative of qualitative) for the non-engineered part of the storage system relies heavily on expert judgment. Certainly compared to the assessment of failure rates used in QRAs for industrial installations, which is more based on historic figures for failure rates. For the failure scenarios for CO_2 storage in general no historic data are available [151]. The expert judgments used instead are mainly based on experience in the oil and gas industry, from natural analogue studies and through modeling [94,98,151,152]. This provides

Table 9
CO_2 containment issues and their mitigation/remedial measures suggested in EIA procedures for CO_2 storage projects and general literature on CCS.

Environmental concerns regarding CO_2 storage	Mitigation/remediation	Source
Leakage and seepage through/alongside Caprock: -Catastrophic failure and quick release -Gradual failure and slow release	-Injection/reservoirs pressure lower than initial pressure -Injection pressures up to 85 percent of fracture gradient[a] -Control composition CO_2 -Avoid fracturing conditions -Stop injection, remove CO_2 from reservoir -Detecting leakage (mass balance, seismic monitoring, monitoring impact zone)	[94,121]
-Leakage along wells including shallow accumulation -Upward leakage through existing deep oil and gas wells	Monitoring: -Pressure in annulus of the well -Analysis for gas in well annulus Mitigation: -Use state of the art drilling and completion techniques -(Re)completion of unused wells -Reworking deep wells -Appropriate plugging of wells -Early abandonment if well integrity is doubtful. -Common O&G industry mitigation techniques for leaking wells	[94,113,120,121]
Release through induced faults resulting from increased pressure (local over-pressure)	-Determine induced/activated fractures through seismic monitoring -Detect micro-seismicity -Alter injection strategy -Reduce injection pressure -Venting CO_2 from reservoir -Move to another injection well -Water production from reservoir	[94,120,121]
Leakage into non-target aquifers due to unknown structural or stratigraphic connections and due to lateral migration beyond spill point	-Stop injection -Remove CO_2 accumulation	[94,121]
Upward leakage through undocumented, abandoned, or poorly constructed wells	-Survey field for existing wells -Remote sensing (through satellites), atmospheric monitoring, surface and near surface monitoring and subsurface monitoring.	[94]
Induced fracturing (as consequence of UGS injection/production cycle)	-Monitor and control of temperature and pressure of CO_2 -Minimal distance injection well and fault: −200 m	[113,126,162]
Effects of pressure development due to injection/production -Earth subsidence or uplift -Seismicity	Monitoring: -Seismographic -Water leveling Mitigation: -Production of reservoir fluids	[113,119]
Leakage to near-surface environmental compartments	-Sanitize groundwater -Sealing well zone -Building modification	[120,141]

[a] The pressure required to induce fractures in rock at a given depth.

a perspective on the order of magnitude of the probability of failure, but cannot be compared with the more certain failure rates used in QRAs for engineered systems. The failure rates for non-engineered system are in addition highly site specific as they depend on site-specific geological characteristics. The geographical extent and natural heterogeneity of a failing system makes it also possible that there is a spatial distribution of the rate of failure and thus of risks.

5.3.2. *Results and indicators*

The indicators that are used to report on the consequences are typically: the fraction of injected amount leaked (in %), the total amount leaked (in t CO_2) and the flux (in t m^{-2} yr^{-1} or t yr^{-1}). Table 8 shows that the RAs deal with various environmental compartments. The subdivision of environmental compartments is not equal in all studies. The indicator (most often the flux) is sparsely presented for multiple environmental compartments nor is the entire pathway of the CO_2 including multiple compartments presented with the use of quantitative indicators.

A performance indicator for the reservoir for which also a safety limit is suggested is the reservoir pressure. In the Barendrecht project it was stated that the reservoir pressure may not exceed 95–97.5% of the initial reservoir pressure before gas production due to injection of CO_2. For aquifers such a limit should also be developed.[20] Indicators that have been presented in EIAs and RAs for compartments other than the reservoir comprise the concentration of CO_2 expected in the groundwater and atmosphere [94,149]. Based

[20] In the Gorgon project where the CO_2 is injected into an aquifer, a pressure management program is developed to ensure that reservoir pressure is 'below acceptable levels'. Quantitative description of what such a level would be, or what the expected reservoir pressures are, is however lacking.

on literature some basic performance indicators per compartment can be suggested, although site specificity of geological storage may require an unique set of performance indicators:

- Reservoir: pressure, temperature and location of CO_2;
- Well: annular pressure, gas composition well annulus;
- Groundwater: pH, CO_2 partial pressure, concentration of As, Ba, Pb and Zn;
- Overburden: amount of CO_2 (or other displaced substances) in non-target reservoirs;
- Soil: CO_2 concentration, earth subsidence/uplift;
- Atmosphere: CO_2 concentration.

As far as we can ascertain, no formal guidelines are set to limit the concentration of CO_2 in compartments other than the atmosphere. Stenhouse et al. [143] use existing (US) limits for groundwater and implicitly suggest using the concentration of lead in groundwater as an indicator for the performance of the CO_2 storage reservoir. Then it is possible to estimate the maximum amount of CO_2 that is acceptable to leak into the groundwater from the geosphere, yielding a limit for the indicator. Wilson and Monea [148] propose limits (see Table 8) for the flux of CO_2 from the geosphere into the atmosphere based on concentration limits for CO_2 in the atmosphere. Saripalli et al. [151,152] have set concentration thresholds for several environmental compartments and biota. These studies thus provide preliminary tools to develop risk acceptance criteria.

There are very few indicators for concentrations or consequences reported in RAs and EIAs. These indicators are reported in the studies that include an atmospheric dispersion model. For instance, in the Ohio River Valley case indicators for consequences are presented. Although a simple dose-effect relationship was assumed, this is the only RA that reports quantitative indicators up to the level of 'impact' (not just flux or effect on concentration) for several relevant environmental compartments, with the note that consequences of elevated CO_2 concentrations are highly dependent on local conditions. For human safety also an 'impact' indicator is suggested in the FutureGen project. This is however not an indicator based on dose-response modeling.

Furthermore, it is important to stress that it is very difficult, if not impossible, to assess the location where the CO_2 may enter the biosphere in case of a leakage other than a leaking well. Drawing iso-risk contours, an indicator for the possible impact used in some countries, to depict external safety on a topographical map is thus not possible for all leakage scenarios. When setting norms for such indicators they should be tailored to CO_2 storage to cope with uncertainties regarding the spatial distribution of probabilities of failure and its impact.

It can be conservatively concluded from Table 8 that leakage along or through a well bore is the scenario with the highest indicator values, suggesting the highest risk. Furthermore, if co-sequestration of H_2S is to be applied it should be taken into account that the RA outcomes presented here show higher risks for H_2S than for CO_2, even when present in low concentrations.

It should be noted that the results of the RAs presented in Table 8 represent the results of worst-case scenarios and not that of likely scenarios for the evolution of the storage reservoir. These results can be used to conservatively compare failure scenarios and to develop appropriate monitoring plans, as well as plans for mitigation and remediation of risks.

5.4. Monitoring, mitigation and remediation

5.4.1. Monitoring

Monitoring various environmental compartments before, during and after closure of CO_2 injection projects is crucial to understand the fate of the injected CO_2, the effects it has on the reservoir and surrounding, and possible impacts of leakages. It is furthermore essential to calibrate and possible improve the models that are used to assess the future (short- and long-term) state of the CO_2 in the subsurface, see Fig. 3. Finally, monitoring is required to assess the effectiveness of remedial actions. It is however stressed in literature that monitoring of the deep subsurface inherently comes with uncertainty and is expected to remain so in the future, despite developments in monitoring tools [124,155].

The 'new' part of the monitoring plan for CO_2 storage projects is aimed at monitoring the containment of CO_2 in the underground. Several techniques[21,22] are proposed for different phases of the project (see also Fig. 3) to monitor various environmental sub-compartments, being: the underground (including reservoir and wells), the overburden and the biosphere (including atmosphere, groundwater and surface water). From these three sub-compartments the reservoir and wells are predominantly monitored, with the principal function to control the injection process. Monitoring of the biosphere is new compared to the standard in oil and gas industry [121]. Further additions compared to the oil and gas industry include: remote sensing (with satellites), more frequent seismic surveys and the employment of more monitoring wells in the soil layers above the reservoir [122].

An observation that we made from reviewing the monitoring plans is that the monitoring of CO_2 storage projects focuses on assessing indicators for containment (i.e. possible leakages) and measuring the state of the reservoir and overburden. Considerably less attention is paid to indicators measuring possible impacts on target species. An example for this observation is presented in the EIA documents for the Gorgon project for which no definite monitoring plan[23] is yet provided. However, provisionally it is aimed at: monitoring the CO_2 plume migration in the subsurface with time lapse (4D) seismic techniques, surveillance of surface CO_2 fluxes and monitoring injection characteristics (e.g. pressure and rates) [118,119].

Monitoring tools are essential to measure the performance indicators and make benchmarking against the norms possible. It should be stressed however that the accuracy of measuring these indicators for the deep subsurface is challenging and comes with uncertainties. When formulating norms for the various environmental compartments this should be properly acknowledged. The development of norms and a site-specific optimal set of monitoring tools and plans should thus be in close harmony.

5.4.2. Mitigation and remediation

In conjunction with monitoring also preventing, mitigating or remedial actions are crucial. These actions may counteract the occurrence, effects and impacts of failure of the injection and

[21] This encompasses techniques to monitor: the injection and monitoring well (annular pressure, integrity of casing and cement, CO_2 concentration), pressure around the well plugs, presence and distribution of CO_2 near the well, small leakages around the wells with acoustic surveys, surface injection flux (debit, quality, temperature and pressure), subsurface pressure and temperature in well and reservoir, seismicity, ground movement and CO_2 concentration in air and groundwater near wells.

[22] An overview of monitoring techniques that are (to be) used at currently operating or planned injections sites (In Salah, Sleipner and Snøhvit) is presented in [157]. It encompasses surface and subsurface monitoring, the latter being subdivided into seismic and non-seismic monitoring. More extensive overviews and selection support tools for monitoring techniques are presented elsewhere, i.e. see [158,159].

[23] The following statement is made: "While not directly aimed at detecting impacts from migration of reservoir CO_2 on the environment, these monitoring programs will provide verification with respect to any impacts from reservoir CO_2 leakage."[119].

storage activity. Furthermore, improving mitigating techniques for CO_2 storage is according to Singleton et al. [160] crucial for facilitating public acceptance.

For CO_2 pipelines, an engineered system, risk mitigation options are readily available. This is different for the non-engineered subsurface part of the CO_2 storage activity for which the mitigation options are still under development. Minimizing risks starts with the screening and selection of suitable reservoirs. This is followed by detailed characterization of the reservoir and identification of faults, fractures and (abandoned) wells (i.e. possible leakage pathways) which comes with uncertainty [94]. The configuration, location, design and completion of wells form also an important part of a strategy to reduce the risk of leakage. The injection strategy then also should take into account the expected pressure development in the reservoir to prevent unwanted processes in the reservoir and its surroundings. Then mitigation and remediation can be aimed at the possible source of the CO_2, which are the wells and reservoir, or aimed at the environmental compartment that is affected by the leakage. Benson and Hepple [153] as well as Cooper [124] have presented an overview of possible mitigating and remedial actions that can be summarized and simplified as actions to:

- Lower reservoir pressure to mitigate CO_2 leakage and other consequences by altering the injection strategy (pressure, rate, total volume) and producing water or eventually CO_2 from the reservoir;
- Carry out the recompletion, workover or plugging of (abandoned) wells to mitigate CO_2 leakage;
- Remove the accumulated CO_2 from the environmental compartment in the subsurface where it has leaked into. (In the case of leakage into groundwater, the groundwater can be produced, cleaned and reinjected);
- Dilute the CO_2 to remediate impacts of exposure to CO_2, e.g. with fans or even helicopters[24] in the case where CO_2 has leaked into the atmosphere.

In Table 9, a more detailed overview is presented of monitoring, mitigation and remedial actions that have been proposed in scientific literature and in EIA procedures for CO_2 storage projects.

Reviewing existing mitigating and remedial actions yields the insight that mitigation is aimed at controlling leakages from the well and reservoir as these are considered the most important failures. Mitigating actions for the overburden and near surface are addressed only very limited at present. Considering the importance of public acceptance in CO_2 storage projects and the role risk plays in that process it is deemed necessary to focus on developing more possibilities to mitigate and remediate risks, taking into account all environmental compartments.

5.5. Findings geological CO_2 storage

In the risk assessments and EIA procedures typically the following failure scenarios are assessed: well failure, caprock failure and leakage through faults or fractures. It is, however, not formally put down in risk assessment guidelines whether or how these scenarios should be derived and assessed. Currently, different approaches for the RA exist with their own merits and limitations. Moreover, the execution of a risk assessment of CO_2 storage is highly site specific and for a considerable part based on expert judgment. This implies that significant emphasis should be put on how - in addition to which - failure scenarios are developed, selected and assessed.

Further, models of sub-compartments (vadose zone groundwater, surface water bodies, atmosphere, reservoir, overburden and well) are extremely limited and are being improved or being developed to deal with CO_2. Maul et al. [146] however rightfully conclude that 'the development of models that satisfactorily represent the whole system remains at an early stage'. The next step is thus to integrate or correctly couple these models to make an assessment possible for all relevant performance indicators (e.g. pressure, CO_2 concentration, pH, amount of CO_2 leaked, temperature etc.). This also stresses the importance of formulating clear performance indicators and thresholds for them. With it, also a clear distinction between the environmental compartments possibly affected by CO_2 storage should be pursued.

To assess the possible consequences of leakage scenarios, fluxes of CO_2 between environmental compartments can be modeled or estimated, though with significant uncertainty. However, using these fluxes to assess effects and impacts on the various organisms and ecosystems present in the various environmental compartments is currently a missing link. We recommend therefore that dose–response models for ecosystems or target species are developed and applied, taking into account site specificity.

The assessment of failure rates for most of the possible leakage scenarios lacks an empirical base and is heavily dependent on expert judgment. There is also no methodological standard on whether and how these scenarios should be modeled to estimate the risk using quantitative indicators.

To deal with the uncertainties mentioned above, we recommend a stepwise approach starting with an intensive (e.g. annual) evaluation cycle of CO_2 storage activities, including: planning, modeling, monitoring, verification and calibration, evaluation, planning etc. This iterative cycle should focus on the operational phase and post-closure phase. With assuring monitoring results it then can be decided to gradually reduce the frequency of this cycle and reduce the intensity of monitoring depending on the outcomes of an evaluation using above recommended performance indicators.

A best practice guide could be a platform to implement these recommendations. For aquifers a best practice guide for the design and operation of CO_2 storage projects is developed by Chadwick et al. [163]. The development and integration of best practice guides for other geological reservoirs would be valuable too, as it would reduce the uncertainty for both operators and regulators regarding the design and operation of the CO_2 storage project. Furthermore, it would on a more strategic level ease the screening and selection of storage reservoirs. This is pursued to be filled with the CO_2 QUALSTORE project [164–166]. The CO_2QUALSTORE

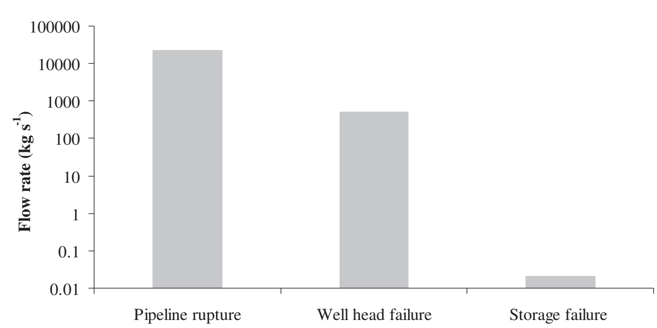


Fig. 4. Maximum flow rates reported for failure scenarios in risk assessments for CO_2 transport and storage activities reviewed in this study.

[24] Following an unwanted release from the CO_2 fire suppressing system in a factory in Mönchengladbach (Germany) helicopters were used to force dispersion of the CO_2 [161].

Table 10
Key issues in the assessment of environmental interventions regarding CO_2 capture, transport and storage.

	Indicator	Models/tools	Regulations
Capture	- Atmospheric emissions quantified but uncertain. Co-benefits (PM, SO_x, HCl, HF) and trade-offs (NO_x, NH_3) probable due to application of CO_2 capture. Depends on applied capture technology. - Emissions of solvents and degradation products (focus: post- combustion). - Limited quantitative data available on emissions to water and solid waste streams. - Water consumption increase due to capture.	- No reliable emission factors for emissions to water and air. No model seems available that models waste generation for capture technologies (focus recommended: coal fired post-combustion and oxyfuel). - Possibly adaptation to atmospheric models needed to cope with 'new' emissions due to capture. - See transport for issues of release and dispersion modeling of CO_2 from the engineered system.	- No BREF and BAT - Should emission standards take into account efficiency penalty? - Emission and concentration norms for solvent emission and their degradation products should be formulated.
Transport	- Characteristics of released content are, within boundaries, uncertain. Maximum reported release rate is 22 t s^{-1}. - Concentration of CO_2 and impurities in surrounding of a failed pipeline is assessed to be above concentration thresholds at up to 7.2 km. - Impact (1×10^{-6} risk contour) of CO_2 pipelines is assessed to be possible up to 3.3 km based on a concentration threshold. With a preliminary probit function this contour extends up to 204 m.	- Probability of infrastructure failure requires scrutiny. - Release models should include impurities and thermophysical properties. - Release/dispersion model validation for high-pressure CO_2 release. - Dose-response models (e.g. probit function) for target species (or ecosystems) should be developed depending on environmental compartment. Currently, these models are not (yet) available.	- Pipeline standards are absent, although work is performed in this area. - In QRA no standardized failure scenarios are formulated. - No formal limits for release of CO_2 and impurities. - Uniform atmospheric concentration limits for CO_2 to be used in RA. - No formally adopted safety distances for CO_2 pipelines.
Storage	- Characteristics (total amount and speed) of fluxes (e.g. CO_2 and brine) between environmental compartments can be quantified, although with high uncertainty. Maximum release rate from storage activity in reviewed RAs is 0.5 t s^{-1}. - The state (e.g. CO_2 concentration, pH) of a compartment is not frequently reported. - Impact indicators per compartment are reported in RAs although sparsely for risks caused by failure of the geological storage system. No risk contours can be drawn as not all leakage pathways are known. Overall: No clear performance indicators per environmental compartment.	- Failure scenarios are typically: leakage along well and wellhead failure, caprock failure and leakage through faults or fractures and leakage along spill point. - CO_2 dispersion and transport models, reservoir models are not validated for long-term CO_2 storage. - Integration of models for subsurface and biosphere is at an infant stage. - See 'Transport' for issues of release and dispersion modeling of CO_2 from the engineered system. RA Tools rely highly on expert panel to (depending on approach): -Identify and select failure scenarios; -Characterize/quantify failure rates; -Characterize consequences.	- Best practice manuals for CO_2 injection are being developed - Monitoring and reporting guidelines for, and prescription of, the exact characteristics of the injected CO_2 are not formulated - Standardized methodology for the development of failure scenarios and reporting. - Monitoring/reporting standards and limits for fluxes between compartments are absent. - Monitoring/reporting standards and norms specific for the various environmental compartments are absent. - Uniform atmospheric concentration limits CO_2 to be used in RA - Standard Safety distances not formulated.

guideline for selection, characterization and qualification of storage projects stipulates once more that development of project specific performance indicators, targets and norms is an iterative process that requires a dialogue between project developer(s) and regulators. This guideline also recommends that permit review or renewal includes the re-assessment of the risk profile and uncertainties of the storage project. This may include the addition and the up/downgrading of risks. It also may result in the revision of the set of site specific performance indicators and norms.

In conclusion, levels of acceptable risk and the methodologies to assess, measure, monitor and report on those risks should be defined on a case-by-case basis. An iterative and interactive dialogue between the key stakeholders is recommended to ensure that state of the art knowledge is included in the risk management of storage projects. This also contributes to a transparent process that demonstrates the general public how risks and uncertainties are managed.

6. Comparing risks of CCS activities

Comparing the risk of CO_2 transport and storage activities can be done to place these risks into perspective. It is however not judicious to use the results of such a comparison to provide any argument for the acceptance of these risks, see also [167]. A systematic comparison between the risks of CO_2 pipelines and CO_2 storage is rather difficult and could not be done within this study. The outcomes of RAs reviewed in this study for the CCS activities are incommensurable as not all RAs use and present a risk indicator in the form of the product of likelihood and consequence of a failure. It is however possible to compare maximum reported flow rates as is done in Fig. 4.

This flow rate is reported for various failure scenarios of CCS activities and can be considered a proxy for the consequence of the failure. Depending on the magnitude of the flow rate different HSE issues are of importance. High and local flow rates may have an acute effect on human safety. Contrarily, low and dispersed flow rates may have an effect in the case of long-term chronic exposure. This yields the insight that acute effects on human safety are, if at all, more likely[25] for CO_2 transport activities compared to CO_2 storage activities. Furthermore, Fig. 4 indicates that the maximum flow rates resulting from a pipeline or wellhead failure are orders of

[25] This should not be confused with the probability of occurrence.

magnitude higher than that of a leaking well. This neglects however the probability of occurrence and local conditions which are crucial when determining risk with quantitative indicators. Clearly, an equal comparison can thus not be made at this moment.

7. General conclusions

The goal of this study was twofold: (1) to identify and characterize existing and new environmental interventions associated with CO_2 capture, transport and storage that are typically addressed in EIA and SEA procedures; (2) to assess whether crucial environmental information is lacking that may postpone the implementation of CCS projects and plans. To fulfill the goal of this study we carried out a literature study reviewing (analogous) EIA procedures and scientific literature on CO_2 capture, transport and storage.

It should be stressed that it was not the goal of our study to assess whether the knowledge on environmental consequences of CCS is satisfactory to allow competent authorities to issue the permit(s) for CCS activities. This is up to the competent authority or, eventually, the judicial system to decide.

We have however identified several knowledge gaps that deserve proper acknowledgement in a formal decision making process for CCS activities. In Table 10, the key issues regarding the assessment of environmental interventions of the considered CCS activities are summarized. If unresolved, they may have the potential to postpone the implementation of CCS.

For the first step in the CCS chain, CO_2 capture from power plants, we found that changes in key atmospheric emissions (NO_x, SO_2, NH_3, particulate matter, Hg, HF and HCl) are expected. The largest increase is found for the emission of NO_x and NH_3 when equipping power plants with post-combustion capture. A decrease is expected for SO_2 emissions, which are low for all power plants with CO_2 capture. Additional research (measurements and modeling) and regulatory efforts (norm setting) are required to cope with 'new' emissions from predominantly post-combustion CO_2 capture technologies. Furthermore, an increase in water use (32%–93%), resources, and waste and by-product formation is expected per net generated kWh. The composition, volume and mass of these waste streams is not fully known and thus environmental trade-offs by shifting for instance substances from atmospheric to aqueous emissions or to a solid waste stream are not fully acknowledged. We recommend that environmental monitoring programmes for pilot/demonstration plants should help to quantify these issues in further detail.

For the second step in the CCS chain, high-pressure CO_2 transport by pipelines, we found several important knowledge gaps to be present in the assessment of risks of CO_2 pipelines. The foremost gap is the absence of validated release and dispersion models for high-pressure CO_2 pipeline failures. Another challenge is the assessment of the effects of impurities on operation, failure rates and HSE impacts. Considerable research efforts are being undertaken to close these gaps.

We recommend the further development and implementation of guidelines for assessing the risk of (high-pressure) CO_2 pipelines. These should include a definition of the type of failures that should be assessed, the methodological choices to be made, uniform exposure thresholds and dose-response model, and eventually safety distances for CO_2 pipelines.

For the final step in the CCS chain, we found that the safe and long-term storage of CO_2 could be an important issue compared to environmental assessments for current proficient activities in the geosphere. This study has identified several challenges with respect to the assessment of risks. One of these challenges is a detailed characterization of storage formations and overburden. Subsequently, the validation of reservoir models is needed to make the assessment of performance indicators possible. Guidelines have been published to support project developers and regulators in developing site-specific norms and associated performance indicators. This set of performance indicators and norms should inherently linked with action plans for monitoring, mitigation and remediation.

The execution of a risk assessment of CO_2 storage is highly site specific and for a considerable part based on expert judgment. We further conclude that it is currently not possible to execute a QRA for the non-engineered part of the storage activity with high confidence. Uncertainty is however expected to be reduced when learning-by-injecting increases. An iterative and interactive dialogue between the key stakeholders is therefore recommended to ensure that state of the art knowledge is included in the risk management of geological storage projects. This also contributes to a transparent process that demonstrates the general public how risks and uncertainties are managed.

We recommend the further development of guidelines for risk assessment. In absence of a methodological standard, the focus of the guidelines should be on the development of uniform reporting standards, especially, concerning parts of the assessment that heavily rely on expert judgment.

In conclusion, most gaps in environmental information regarding the CCS chain were identified and characterized for the underground part of the storage activity. This holds especially for aquifers in comparison with hydrocarbon reservoirs. This should however not be confused with an assertion on the magnitude of environmental consequences. That is, most environmental interventions and impacts are expected to be induced in the operational phase of the power plants with CO_2 capture.

Regarding the safety of CCS, it is found that the CO_2 release in case of a failure is reported to be the highest for the transport activity. Although the failure of the underground CO_2 storage system appears to have limited consequences, suggesting a low risk, the uncertainty regarding the assessment of the risk has the potential to become a bottleneck for wide scale implementation of CCS if not properly addressed.

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Appendix. Supplementary data

Supplementary data associated with this article can be found in online version at doi:10.1016/j.pecs.2011.05.002.

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U.S. ARMY CORPS OF ENGINEERS ®

Little Rock District

SEDIMENT AND EROSION CONTROL GUIDELINES FOR PIPELINE PROJECTS

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SEDIMENTATION
AMD EROSION CONTROL GUIDELINES
FOR PIPELINE PROJECTS

1.0 INTRODUCTION

The following Sedimentation and Erosion Control Guidelines are based upon acceptable practices in the Little Rock District, U.S. Army Corps of Engineers. All pipeline projects crossing waters of the United States in the Little Rock District shall be constructed using these guidelines. These practices include constructing temporary and permanent erosion and sedimentation control devices properly; stabilizing earthwork; seeding and sedimentation control devices; and maintaining these until the land is permanently stabilized.

One of the most important erosion and sedimentation control considerations is construction time frame. The time between initial disturbances and post construction stabilization is a critical element in minimizing adverse impacts to the environment.

2.0 PROJECTS IN WATERS OF THE UNITED STATES

Pipeline projects crossing waters of the United States are subject to regulation under Section 10 of the *Rivers and Harbors Act of 1899* and Section 404 of the *Clean Water Act*. Section 10 requires permits to authorize certain structures or work in or affecting navigable waters of the United States. Section 404 requires permits for the discharge of dredged or fill materials into waters of the United States. Wetlands are considered waters of the United States and also require Section 404 permits for crossings. The area of pipeline projects which must maintain erosion control in connection with Department of the Army permits are all crossings of waters of the United States and the slopes which drain directly to the waterway.

2.1 STREAM AND RIVER CROSSINGS

During construction, various preventative measures may be implemented to reduce and minimize impacts to stream and river environments. This section will present the conventional methods and techniques that will be used when crossing streams, rivers, and wetlands.

For pipeline crossings of streams or creeks utilizing conventional open-cut trenching techniques, two (2) plans are proposed for sediment control in the stream or creek bed.

Plan #1 is used when streams are small and perhaps intermittent, usually these streams are not considered navigable. Plan #2 is used when a stream has greater velocities and the flow must be maintained. It is used on streams/creeks that are considered navigable by the U.S. Army Corps of Engineers.

Plan #1 is proposed when the stream bed has solid rock and silt or mud present. This plan requires straw bales/silt screening be installed across the entire width of the stream downstream of the construction (trench) area. The straw bales/silt screenings are held in place by installing wire cables and or stakes downstream of the straw bales/silt screening. Sediment controls are installed prior to any construction activities in the stream bed and remain in place until all construction activities in the stream bed are completed. All ground contours are returned to their original condition. Figures 1A and 1B (Appendix) illustrates Plan #1.

If the flow of the stream is too swift to maintain silt screening, additional measures are required. An effective method which can be used is a water dam. Water dams function like small cofferdams. They can be placed where it is necessary to stop, slow, or manage the movement of water. They are temporary barriers built of "inner" tubes of water contained within heavy duty tubing. It can be used virtually in all locations including remote and uneven terrain and does not contribute to sedimentation in the stream.

Plan #2 is proposed when the stream has sufficient flow to prevent the implementation of silt screens across the entire width of the stream. This plan uses a turbidity curtain which is custom designed for the proposed work area. It may be used alone or as a sediment control encircling a cofferdam. The turbidity curtain has a flotation boom and a weighted bottom load line which allows sediment to settle to the stream bed from the bank thus minimizing the impact of equipment in the stream. All ground contours are returned to their original condition. Figures 2A, 2B, and 2C (Appendix) depict turbidity curtains for Plan #2.

If conventional trenching methods cannot be used, the directional drilling method may be used on major river and stream crossings and environmentally sensitive areas. When directional drilling is required as part of Department of the Army Permit, it shall be specified in the permit letter. This method of installing pipelines is well documented as having the least negative impact on environmentally sensitive areas and wetlands. Plans for directional-drilled crossings shall include the location of boring sites and temporary work areas for welding line pipe, as well as the drilling rig and other necessary equipment. The area from the boring sites to the water's edge normally will not be disturbed; however, if clearing of this area is needed, and this area is a wetland, it will be done using hand tools. If dozers, graders or other mechanical equipment will be utilized in clearing, and if the area is a wetland, an additional Department of the Army permit is required for such clearing. Silt fencing will be erected near the river's bank to prohibit the introduction of silt or debris into the water. Additional straw or hay bales will be incorporated to prevent introduction of silt or sedimentation from the boring sites into the water.

Where the pipeline crosses a waterway either by the open-cut method or the directional drill method, straw bales and silt fencing will be used until the revegetation program has matured sufficiently to stop the flow of silt into the water. Silt fencing and hay bales will be erected prior to any other ground disturbing activity. Fences and silt barrier hay bales will be maintained and remain in place as long as required to minimize any negative impacts on water quality. Permanent revegetation will proceed as rapidly as possible after pipeline operations are completed at the crossings.

On river and stream crossings where the open-cut (trench) method is employed, the dredged or excavated material will be kept to a minimum. The work shall be conducting in such a manner to minimize turbidity of the water in the work area and downstream. Excavation of the pipeline trench will not result in the relocation of any existing stream or river channel or restrict stream flow. Any temporary fill placed in the stream such as for road crossing shall be constructed of wooden mats or clean non-eroding material and shall be properly maintained to minimize erosion and degradation of water quality (Appendix, Fig 3A and 3B). Additional Department of the Army permits are required for temporary fills such as road crossings and cofferdams. Sufficient waterway openings such as culverts shall be provided to allow for the passage of expected high flow.

Any temporary fill or excess excavated material from the stream or riverbed will be removed and disposed of in an approved area. If additional fill material is required for bank stabilization, these materials will be obtained from an approved borrow pit.

2.2 WETLAND CROSSINGS

Construction across wetlands should be performed so that the disturbance of wetland vegetation is minimized. After construction, the wetland crossing must be restored to preconstruction bottom contours and maintained in wetland vegetation. If proper construction procedures are followed and the hydrology of the site is not adversely affected, the wetland should naturally revegetate.

Construction methods should minimize the extent of construction equipment usage in wetland areas. Trenching equipment and backfilling equipment working in wetlands shall be placed on mats or mud boards.

One approach would be to prefabricate sections of pipe on dry ground and pull them into place between mud boards which would support construction equipment. Using this same technique, mud boards would also be used to support trenching and backfilling equipment. Spoil can be side cast in a ridge along the pipe trench. Gaps 50 to 1000 feet wide shall be left at intervals of about 500 feet to provide for natural circulation or drainage of water. The top 6 to 12 inches of the trench is required to be backfilled with topsoil from the trench. Excess backfill shall be disposed of on dry land rather than in wetlands. In no instance shall additional fill be placed on any wetland or flood plain area.

In addition, wetlands adjacent to streams will be protected so that they are not adversely impacted by pipeline construction in the streams. These wetlands will not be used for storage, waste, access, parking, borrow material, or any other construction support activity.

3.0 SEDIMENTATION AND EROSION CONTROL

For pipeline projects requiring a Department of the Army permit, the following generic temporary and permanent measures for erosion control are outlined as appropriate methods to follow. The most important measure of erosion control is minimizing the period of time between right-of-way clearing and final restoration. Inadequate erosion control methods, especially on pipelines constructed in steep, hilly regions creates the potential to introduce large amounts of sediment and silt into streams or wetlands at the base of the slopes. Any slope draining into the project crossing greater than 10 percent will have appropriate erosion control measures to minimize erosion.

Temporary measures for erosion control include mechanical barriers to confine sediment and block its entry into the waterway, and temporary seeding methods to revegetate raw earth left exposed during construction. Permanent measures for erosion control involve grading to previous contours, permanent revegitation methods, and follow-up inspections to monitor the success of seeding, with additional seeding if necessary.

3.1 TEMPORARY MEASURES

During pipeline construction, various preventative measures may be required to minimize the potential for soil erosion and stream siltation. Minimizing the time of exposure of disturbed ground is a primary objective. It is extremely important that any soil or stream disturbances of the work area be stabilized as work is proceeding. This section outlines the methods to be used where impacts to waters of the United States have the potential to be significant. These measures are temporary in nature and some of them may be removed after all construction activities are complete. Others may be retained in place when permanent controls are implemented.

3.1.1 SEDIMENT BARRIERS

Natural vegetation acts as an effective filter medium to remove silt from surface run-off. The use of natural vegetation is the most cost-effective means of sediment control and generally results in less overall disturbance to the land than other methods. This technique is therefore applied wherever practical. In areas where natural vegetation is not present or where it is not sufficient to attain the needed removal of silt, installation of sediment barriers is required.

Sediment Barriers are typically *Straw Bale Filters* or *Silt Fences*. They are typically installed across and/or at the foot of a slope or at the outlet or a diversionary structure. Sediment barriers are designed to remove silt from surface run-off. Bale filters are constructed of bales which are securely bound. The bales are embedded at least four inches into the soil and each bale firmly held in place by two stakes driven at least 1 ½ feet into the ground. Bales tightly abut adjacent bales. Straw bales are effective in areas where the support stakes can be driven adequately into the ground. The strings are not placed in contact with the ground. Figure 4 (Appendix) illustrates the design and application of a straw bale filter.

Silt fences consist of fence posts spaced no more than ten feet apart and driven a minimum of two feet into the ground. The above-ground height of the fence posts are no less than two feet. A metal mesh fence with six-inch are smaller openings is fastened to the fence posts to reinforce the silt fence fabric. The mesh fence stands at least two feet above ground and is buried at least four inches below ground. Silt fence fabric which is reinforced (e.g. Envirofence) may be used without a wire mesh support in low flow areas. Figure 5 (Appendix) shows a typical reinforced fabric silt fence design. In streams and in areas where high flow may be encountered, the silt fence always has a wire mesh to support the fabric. On gentle slopes, the fence need not be reinforced with wire mesh and may be supplemented with hay or straw bales as a primary barrier to aid in collecting silt and potential sedimentation from entering ditch lines and waterways. Sediment should be removed from silt fences when it has been deposited to a depth of 1/3 of the fence. Any silt or sediment removed from the erosion control devices should not be deposited where it will erode into waters of the United States.

Neither straw bales, nor silt fences are very durable when they must be continually moved for equipment to pass through. When bales or fences are not practical, interceptor dikes (discussed below) can be very effective.

3.1.2 INTERCEPTOR DIKES

Interceptor Dikes act as a barrier to run-off water. Earthen berm dikes are better suited to rocky terrain and steep slopes, than either straw bales or silt fences, especially during long rain events. Interceptor dikes interrupt and divert storm water flow of the right-of-way. The dikes are typically constructed with earth-filled sacks or mounded compacted earth and rock. On long slopes, a series of dikes are used. Spacing depends on the severity of the slope. The maximum spacing or interceptor dikes are given in Table 1. These distances may be shortened as situations dictate but shall not be lengthened. Properly used, interceptor dikes prevent storm water run-off from causing extensive erosion of the slope. The drainage area above interceptor dike is stabilized to prevent excessive silt from entering and collecting in the diversion channel. The interceptor dikes are to be extended across the slope into the natural vegetation of either side of the right-of-way. Run-off water is filtered at the outlet end of the dike by a bale filter or silt fence. Sediment should be removed from interceptor dikes when it has been deposited to a depth of half of the dike. Figure 6A (Appendix) illustrates the conceptual design of a terrace or simple diversion berm. A more elaborate design, including a level spreader for dispersing the water flow, is shown in Figure 6b (Appendix).

Trench Plugs are typically used in conjunction with diversion dikes and filter structures. Used in this manner, the trench plug prevents surface run-off from circumventing an interceptor dike by flowing down the trench. Spacing for these installations is related to the severity of right-of-way slopes. Maximum spacing for trench plugs are identical to the spacing requirements for interceptor dikes and are given in Table 1.

TABLE 1

Spacing of Interceptor Dikes and Trench Plugs

Slope	Spacing
5% – 15%	150 feet
15% - 30%	100 feet
30% & or greater	50 feet

3.1.3 TRENCH PLUGS (Breakers)

Trench Plugs or *Ditch Breakers* are similar to interceptor dikes in purpose and construction. They are typically constructed of earth-filled sacks (or suitable alternatives such as synthetic foam). Trench plugs prevent erosive run-off velocities from developing in the trench in the same manner that diversion berms accomplish this goal on the disturbed right-of -way. The trench plug serves to form a catch basin for run-off in the trench, trapping the soil and preventing it from being washed out of the trench. Spacing for these installations is related to the severity of right-of-way slopes. Guideline spacing for trench plugs are identical to the spacing requirements for the interceptor dikes given in Table 1.

3.1.4 TRENCH DEWATERING

Storm water which collects in the trench can be controlled through the use of trench plugs. Water removed from the trench must have the silt removed before it is allowed to enter a natural water body. If time and circumstances permit, the water may be allowed to sit on the trench until the silt settles out. If the water must be removed immediately, it will be filtered. Where appropriate, filtration may be performed by natural vegetation. In the absence of adequate natural vegetation, filtration is accomplished using a bale filter or silt fence. In general, the use of a settling basin to allow silt to filter out is used only when no other options are available. Figure 7 (Appendix) illustrates a typical settling basin.

3.1.5 DIVERSION DITCHES

Diversion Ditches are excavated or graded at selected locations to control soil erosion. They are generally installed above the back slope of cuts to divert run-off to natural drainage channels and to prevent the ground water from running down the cut slope. They may be required along the top of embankments to prevent water from eroding the soil from the slopes before permanent erosion items can take hold.

3.1.6 SEDIMENT BASINS

Sediment Basins are constructed by excavating and grading a storage area to detain sediment-laden run-off from disturbing area long enough to allow sediment to settle out. Straw bale filter barriers or filter fabric barriers shall be used in conjunction with sediment basins when needed. Sedimentation basins shall be removed and obliterated without increasing erosion at the completion of the project. They can be used with other erosion controls in steep areas to greatly decrease sedimentation to streams. Figure 8 (Appendix) illustrates the typical design of a sediment basin.

3.1.7 FLEXIBLE DOWNDRAINS

Temporary *Downdrains* can be installed wherever extremely steep drainage-ways having potentially significant flow are cut by right-of-way excavation and severe erosion of the cut face is likely. Flexible closed conduit type or rigid open conduit type downdrain is installed in accordance with the manufacturer's instructions. The downdrain should be designed and situated such that no by-passing of run-off or leakage occurs. Downdrains should discharge into a stilling basin lines with a 4 inch layer of riprap or other suitable material. Figure 9 (Appendix) illustrates the design of a flexible downdrain.

3.1.8 NONVEGETATIVE SOIL STABILIZATION

Temporary, *Nonvegetative Soil Stabilization* is employed to provide protection against excessive soil erosion over a short time period (less than one year). The method employed is, in general, site-specific. Nonvegetative soil stabilization is used to reinforce vegetative measures and is not required where vegetative stabilization provides adequate long-term soil protection. In general, nonvegetative methods are required in areas which will experience high water flows or could experience high run-off velocities (disturbed slopes steeper than 2:1). Methods employed include *Mulching, Brush Barriers, Netting, Matting* and *Stone Coverage.*

Mulching is a temporary measure used as a deterrent to soil erosion. A determination to place a mulch cover may be made when erosion control is necessary to stabilize slopes or when revegeatation cannot take place quickly enough for proper erosion control.

Mulch consists of straw, hay, or salt hay applied at an appropriate rate (e.g. 70-115 pounds per 1000 square feet (1.5 – 2.5 tons/acre) is typical). Mulch anchoring is implemented promptly where applicable and should be achieved by one of the following methods:

(1) Peg and Twine
(2) Mulch Nettings, Erosion Control, Fabric, Jute Matting (Figure 10, Appendix)
(3) Mulch Anchoring Tools (wood stakes or metal staples)

Brush Barriers are constructed by piling, shaping, and tying brush to form barriers in areas where it is necessary to impede the flow of water carrying silt.

Netting and Matting consists of biodegradable wood fibers, jute yarn, or other materials interwoven with knitted nylon or vinyl monofilament material. It is fastened to the slope with wood stakes or metal staples.

Stone is used to protect a soil surface from being eroded by flowing water. It may be used as a temporary or permanent measure. Stone may be used at such places as flume pipes of downdrain outlets, channel banks and/or bottoms, and disturbed areas subject to the movement of heavy equipment. It should be designed for the slope and width of the stream. Consideration should be given to expected flows in choosing the size and depth of stones.

3.1.9 TEMPORARY SEEDING AND REVEGETATION

In addition to structural control measures, temporary seeding, revegetation, and fertilization are necessary to prevent erosion during and after construction. All disturbed areas are temporarily seeded. Soil to be stockpiled for more than 30 days or disturbed areas on which there will be no construction for 3 months shall be stabilized by temporary seeding. Suggested temporary seeding rates and mixtures are often available from the authorized soil conservation agency in that area.

The need for temporary revegetation of a pipeline occurs when new lines are established during the spring-summer period. If new lines are established in the fall-winter period, a permanent revegetation plan will be used. If the need arises to temporarily revegetate an area during the cool season, it is recommended that a mixture of Austrian winter pea, rye, oats, and wheat be used. This mixture provides considerable height diversity, erosion control and a seed supply to wildlife that will have greater benefits than any single winter planted crop. Generally, fescue is not considered to have any valuable benefits for wildlife. If applicable, fertilizer and lime should be applied at a standard rate recommended for the region by an authorized agency.

The combination of milo, millets, and a suitable mixture incorporated into the temporary revegetation plan provides an excellent structural diversity to the pipeline and should have good benefits in controlling erosion. By combining a variety of annuals, quality seed supplies will be available for a longer period compared to any single crop. Most of the seeds recommended for temporary revegetation can be planted with a broadcast seeder after last frost through July.

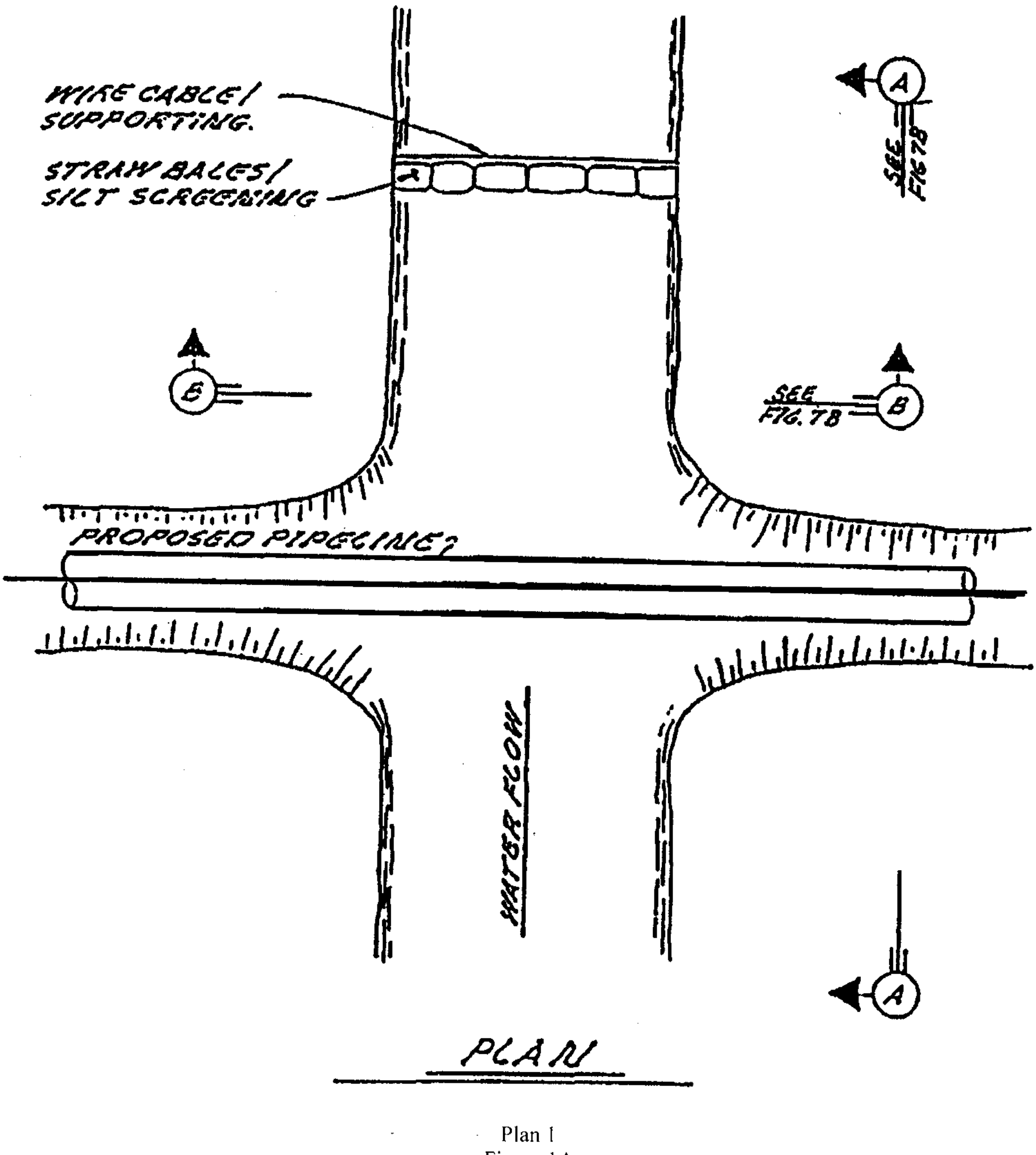
An alternative to temporary seeding and revegetation is mulching. In extremely steep slopes, temporary seeding may also require mulching to establish revegetation. A discussion of mulching techniques and rates is given above, under *Nonvegetative Soil Stabilization.*

3.2 PERMANENT RESTORATION MEASURES

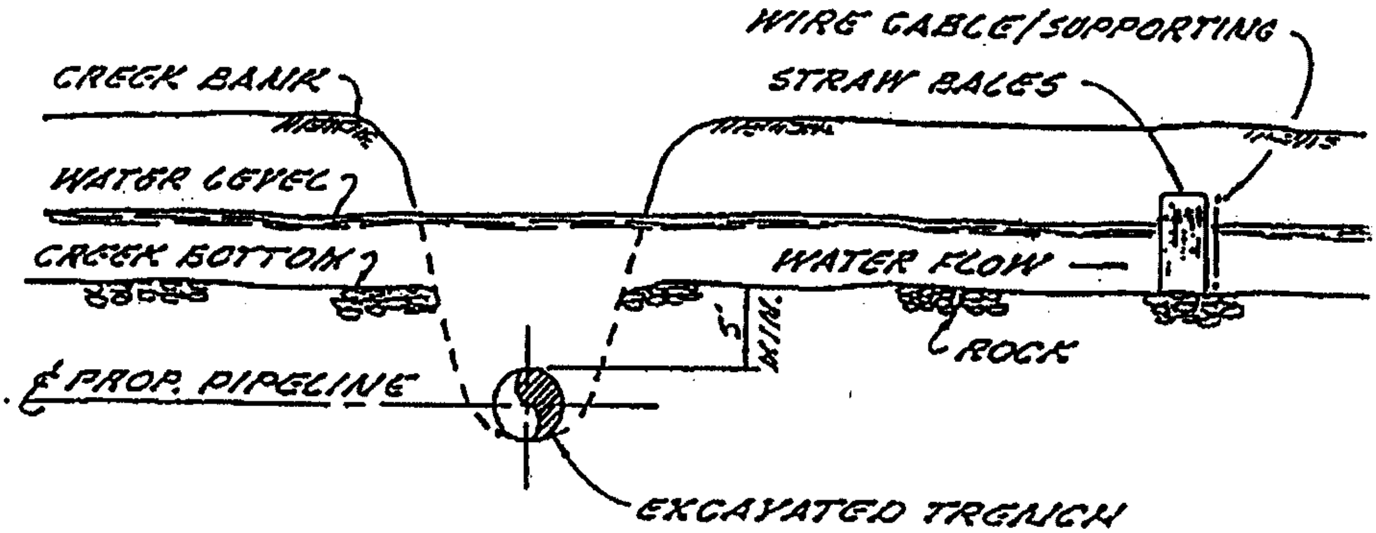
Restoration measures are permanent controls to assure that vegetation is reestablished and significant post construction erosion is avoided. In addition, slopes and waterways within the project area are restored to preconstruction contours. Restoration of each pipeline crossing of a water of the United States must begin as soon as possible following construction. In large projects the time between initial clearing and grubbing and post construction should be designed for final restoration within 14 days of the completion of construction. Clean-up and restoration activities can be summarized by the following general categories. They should be adapted for the specific conditions of the project.

(1) Construct interceptor dikes where needed. This may require leaving dikes used for temporary measures or the installation of additional ones.
(2) Fertilize and lime slopes as needed.
(3) Select seed appropriate for the season of construction and the area. A mixture of seeds (two to five species) is best.

(4) On slopes where vegetative stabilization alone is insufficient, employ nonvegetative stabilization (e.g. mulching). Extremely steep slopes may require matting with staling or lining with more durable materials (e.g. bags of quickrete).
(5) Put sediment barriers such as hay bales, fabric fence or a combination of these where drains and ditches allow sediment to enter the waterway or wetland.
(6) If necessary stabilize the stream banks. Place appropriate materials such as riprap or stapled matting when excessive stream velocities may be encountered.
(7) Remove temporary structures which are not necessary and are not biodegradable. Silt fences installed across a stream downstream of the work site would be an example.
(8) Be prepared to monitor and maintain erosion control measures until stabilization of the area has been accomplished satisfactorily.

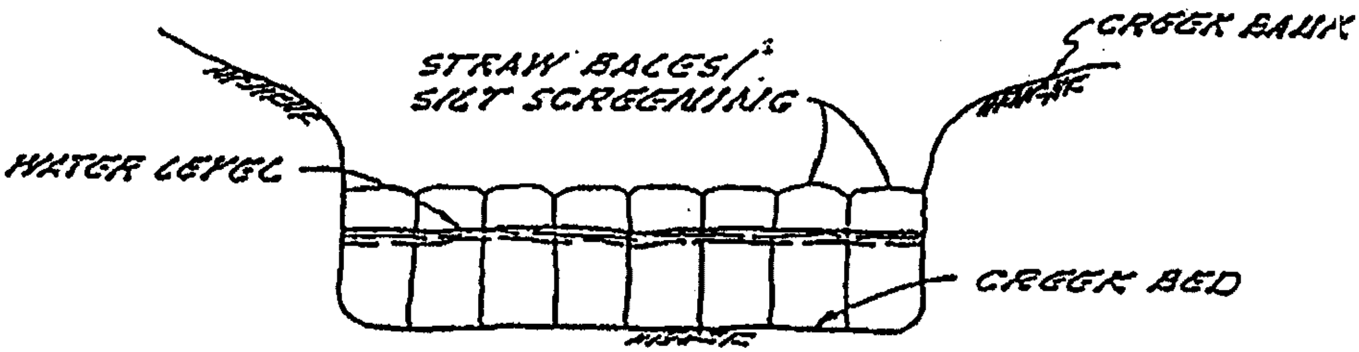


Plan I
Figure 1A



SECTION "A-A"

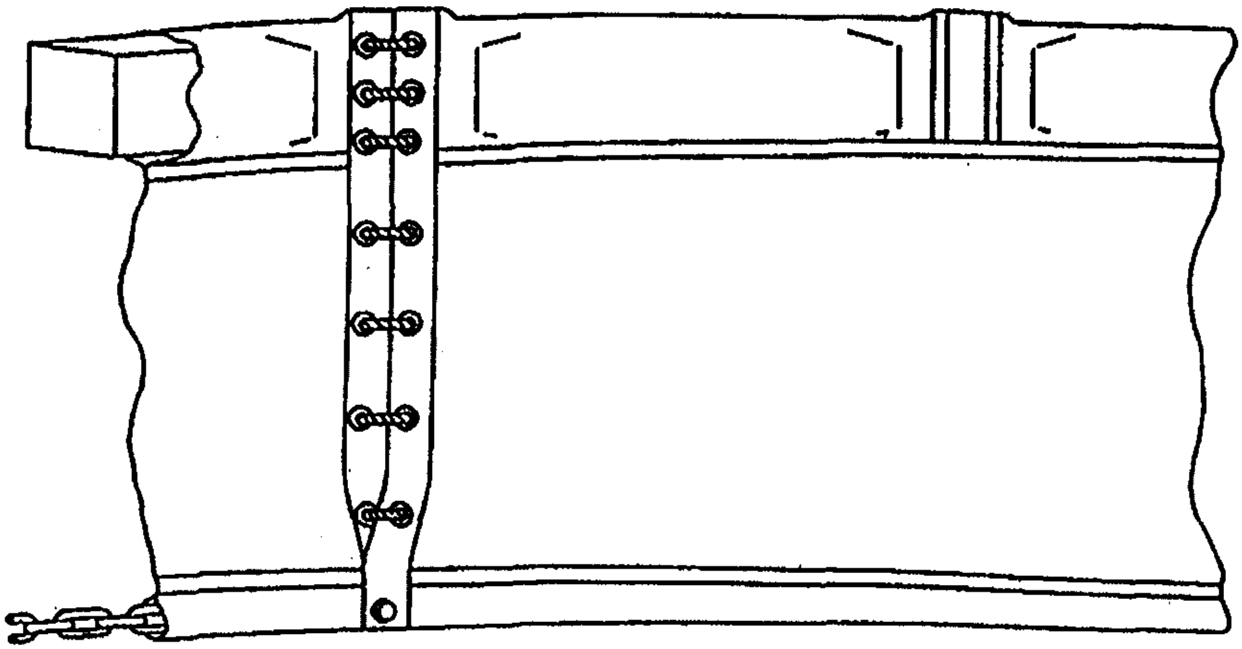
(FROM FIG 7A)



SECTION "B-B"

(FROM FIG. 7A)

Plan 1
Figure 1B



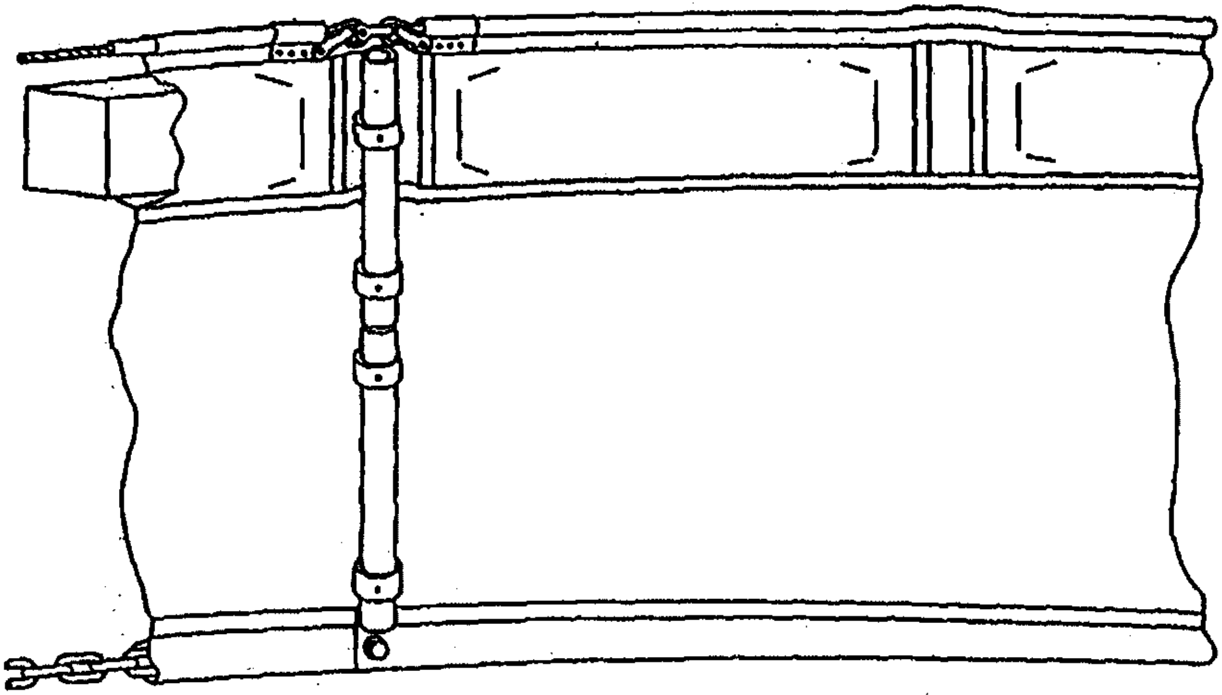
LIGHTWEIGHT
TURBIDITY CURTAIN

APPLICATION:
Calm waters with little current such as lakes, ponds, canals, and shoreline areas.

SPECIFICATIONS

FABRIC	Polyester reinforced vinyl high visibility yellow.	BALLAST/ LOAD LINE	1/4" galvanized chain (.7lb/ft).
CONNECTOR	Sections are laced together through grommets and load lines are bolted together.		
FLOTATION	6" expanded polystyrene over 9lb/ft buoyancy.		

Plan 2
Figure 2A



MIDDLEWEIGHT

TURBIDITY CURTAIN

APPLICATION:

Rivers, streams, open lakes and exposed shorelines with moderate current moving in one direction.

SPECIFICATIONS

FABRIC	**Polyester reinforced vinyl high visibility yellow 18 oz/yd² weight.**	BOTTOM LOAD LINE/BALLAST	**5/16" galvanized chain (1.1 lbs/ft).**
CONNECTOR	**Shackled and bolted load lines with slotted reinforced PVC pipe for fabric closure.**	TOP LOAD LINE	**5/16" galvanized wire rope enclosed in heavy tubing.**
FLOTATION	**8" expanded polystyrene over 19 lbs/ft buoyancy.**		

Plan 2
Figure 2B

TYPICAL BOARD MAT WITH CULVERT(S)
N.T.S.

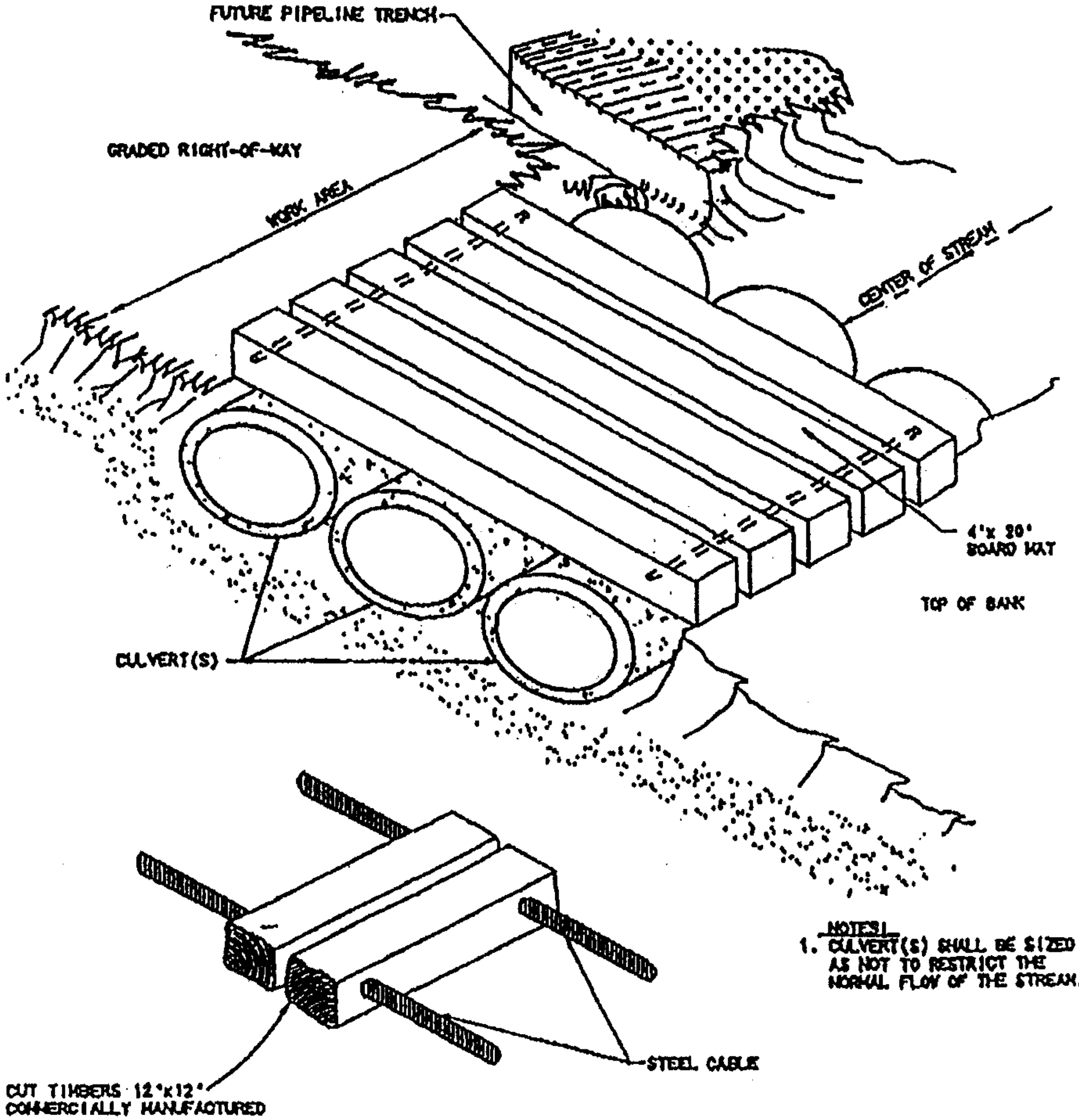
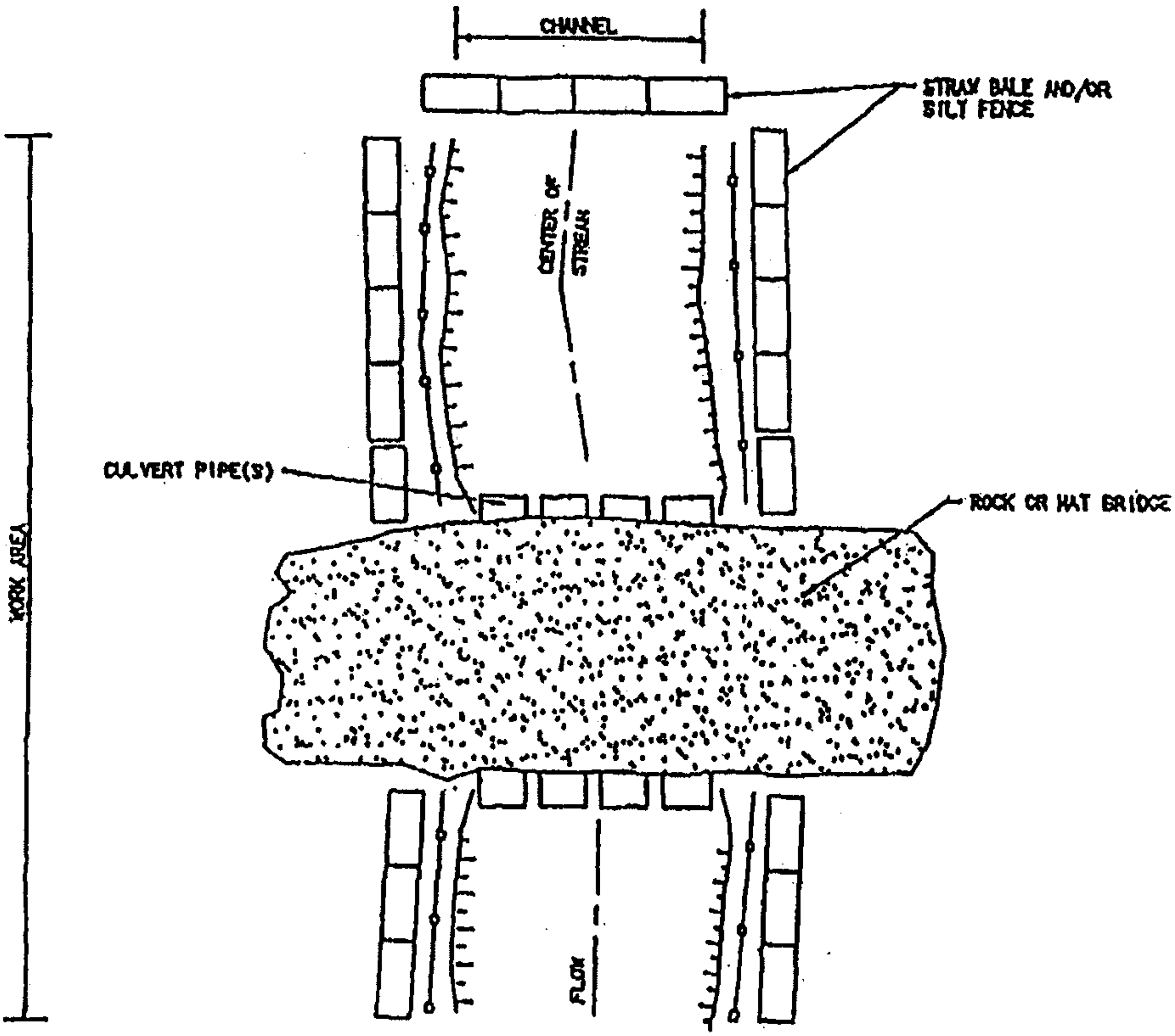


Figure 3A

TYPICAL ROCK OR MAT BRIDGE WITH CULVERT(S)

N.T.S.



NOTE:
1. USE AS MANY CULVERT PIPE(S) AS REQUIRED TO ENSURE NORMAL STREAM FLOW IS NOT OBSTRUCTED BY ROCK OR MAT BRIDGE.

Figure 3B

STRAW BALE FILTER

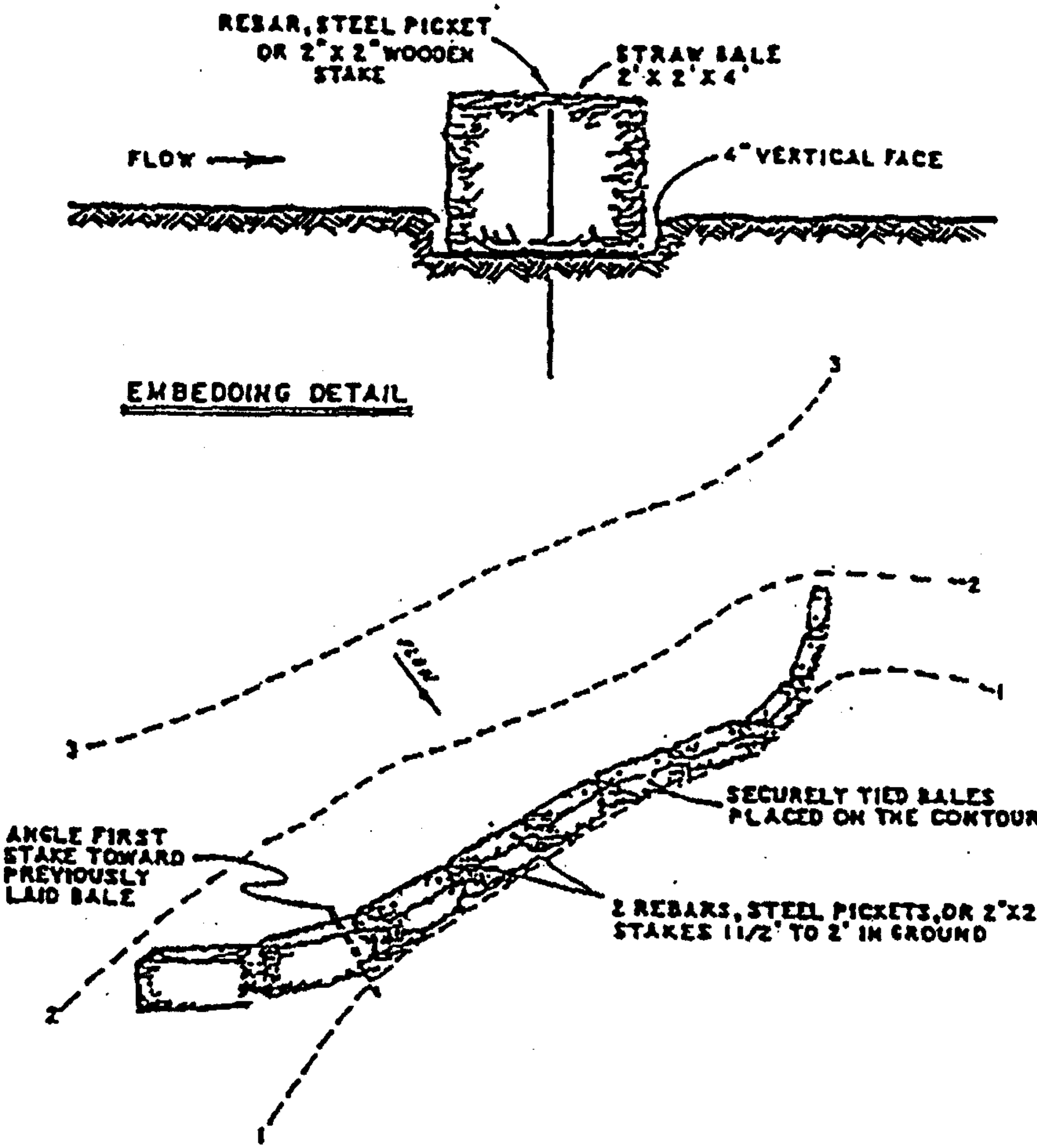


Figure 4

ENVIROFENCE SILT BARRIER

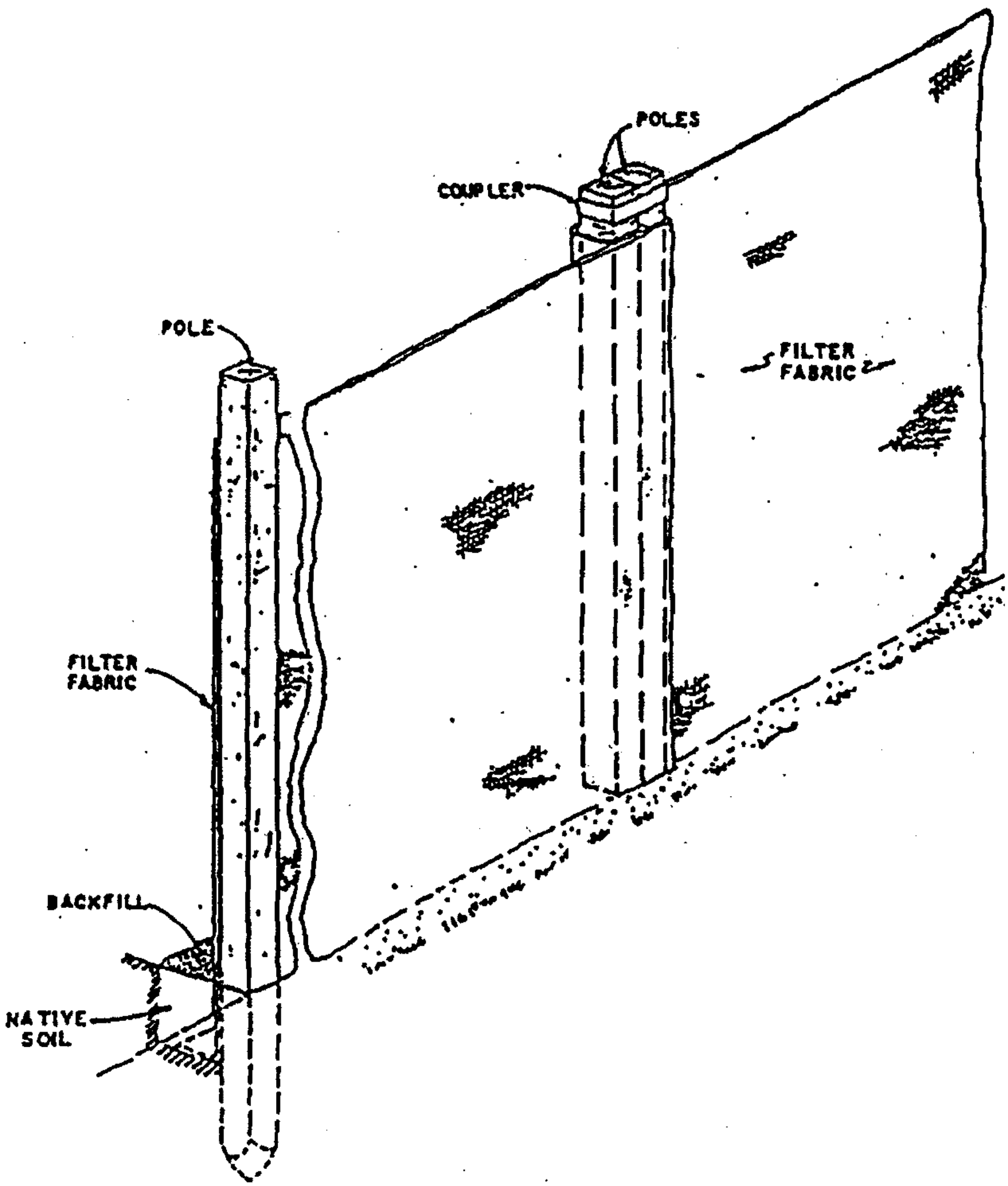
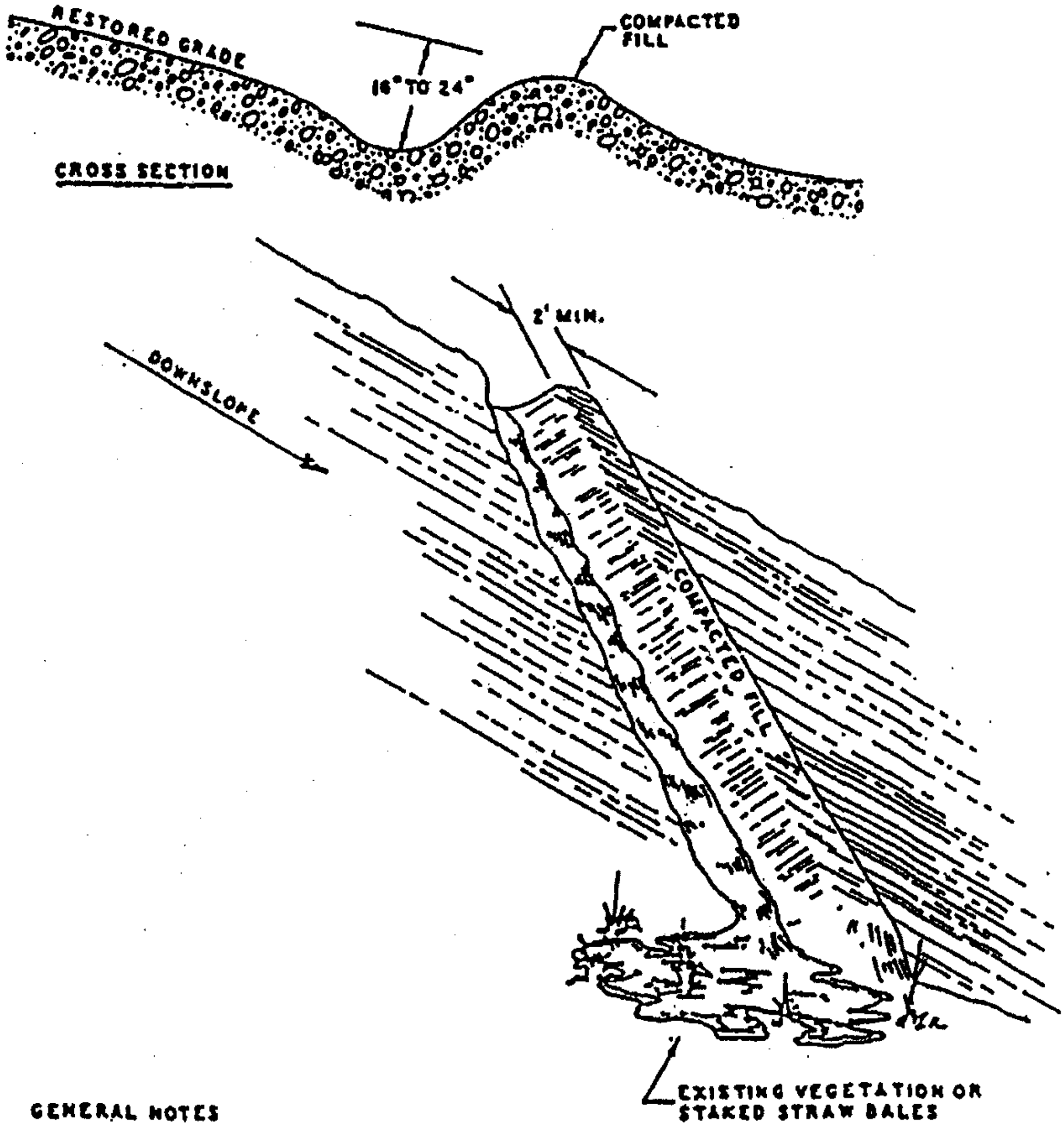


Figure 5

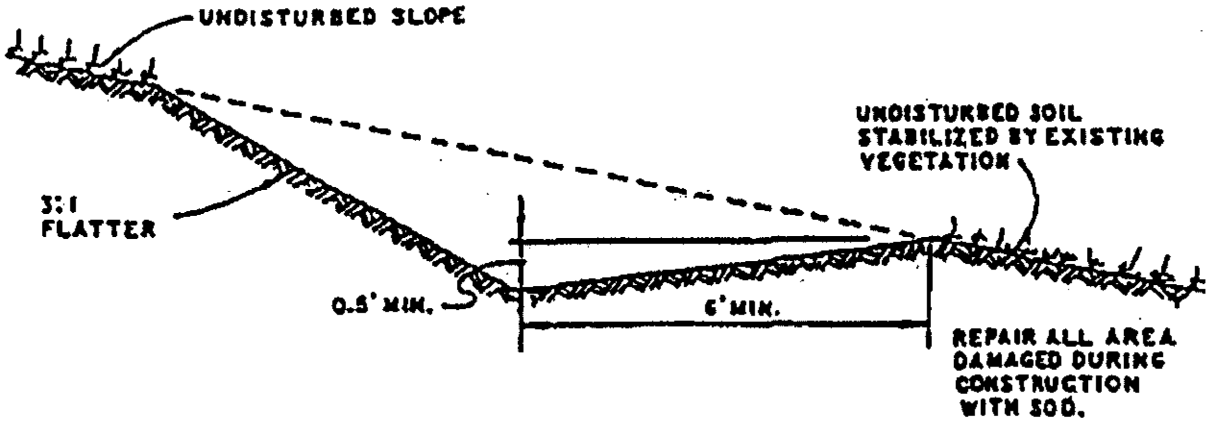
TERRACE



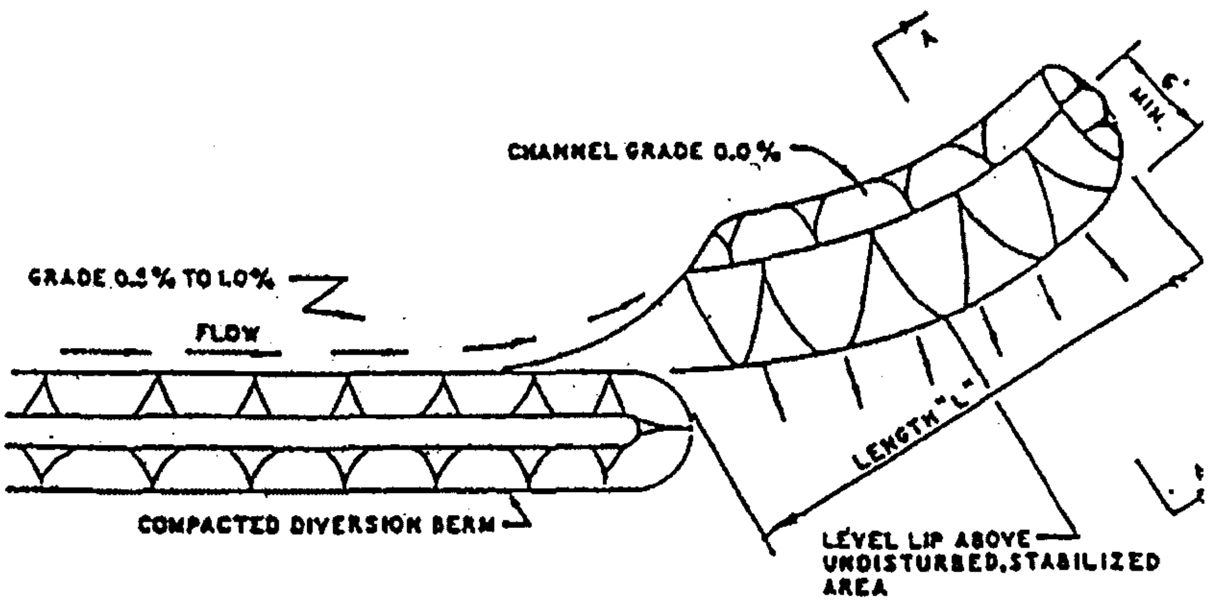
GENERAL NOTES
1. NOT TO SCALE
2. INSTALL ON SLOPING TERRAIN
3. MAINTAIN THROUGHOUT CONSTRUCTION
4. OUTLET INTO AREAS STABILIZED BY EXISTING VEGETATION OR INSTALL STAKED STRAW BALES
5. CONTOUR TO ALLOW PASSAGE OF CONSTRUCTION EQUIPMENT
6. MINIMUM 2% LATERAL SLOPE

Figure 6A

LEVEL SPREADER & DIVERSION BERM DETAIL

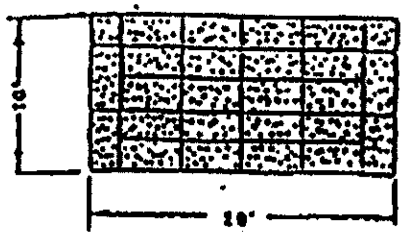


SECTION "A-A" LEVEL SPREADER



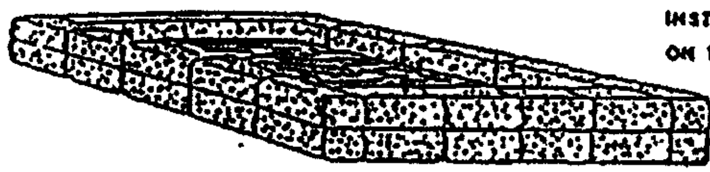
Designed Q_{10} (cfs)	Minimum Length ("L" in Feet)
Up to 10	15'
11 to 20	20
21 to 30	26
31 to 40	34
41 to 50	44
51 to 60	56
61 to 70	70
71 to 80	85
81 to 90	100

Figure 6B



STEP 1

ARRANGE STRAW BALES ON LEVEL LAND TIGHTLY PACKED AS SHOWN TO COVER MINIMUM AREA OF 200 SQUARE FEET, AND SIZED TO HANDLE THE ACTUAL FLOW.

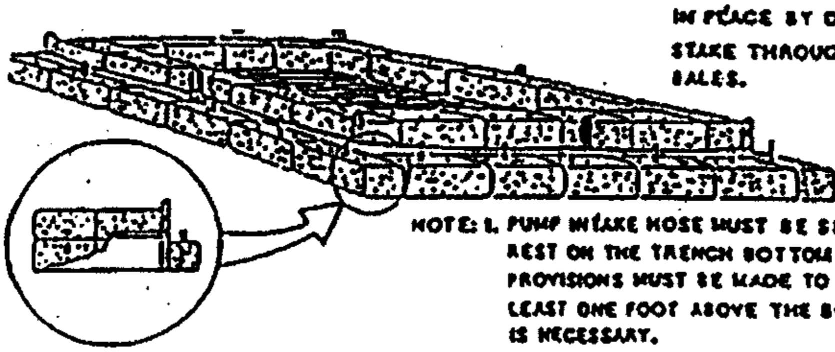


STEP 2

INSTALL ANOTHER LAYER OF STRAW BALES ON THE OUTER EDGE AS SHOWN.

STEP 3

INSTALL SILT FENCE ALL AROUND THE STRAW BALE STRUCTURE AS SHOWN. DIG IN SILT FENCE 6".



STEP 4

INSTALL ANOTHER LAYER OF STRAW BALES ON THE OUTSIDE OF THE SILT FENCE AND SECURE IN PLACE BY DRIVING A REBAR OR WOODEN STAKE THROUGH EACH OF THE OUTER STRAW BALES.

NOTE: 1. PUMP INTAKE HOSE MUST BE SECURED AND NOT BE ALLOWED TO REST ON THE TRENCH BOTTOM THROUGHOUT DEWATERING. PROVISIONS MUST BE MADE TO ELEVATE THE INLET HOSE TO AT LEAST ONE FOOT ABOVE THE BOTTOM UNTIL BOTTOM DEWATERING IS NECESSARY.

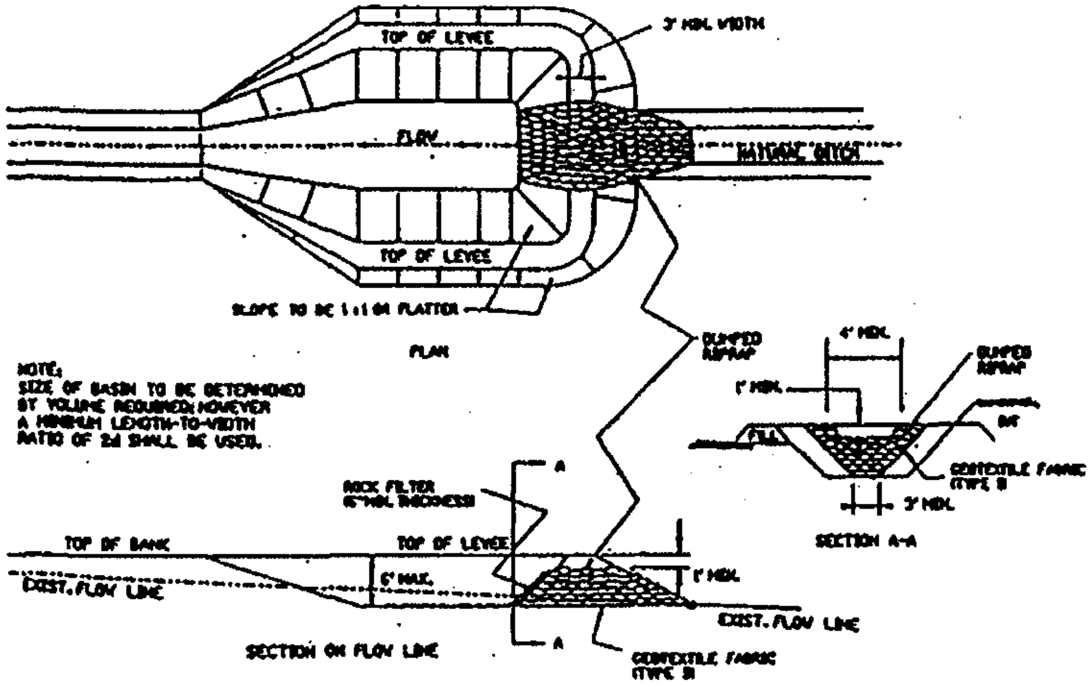
2. WHEN SILT FENCE STAKES CANNOT BE DRIVEN INTO GROUND, LINE THE BOTTOM AND EXTERIOR OF STRAW BALES WITH GEOTEXTILE FABRIC.

EROSION CONTROL DURING PIPELINE DITCH DEWATERING

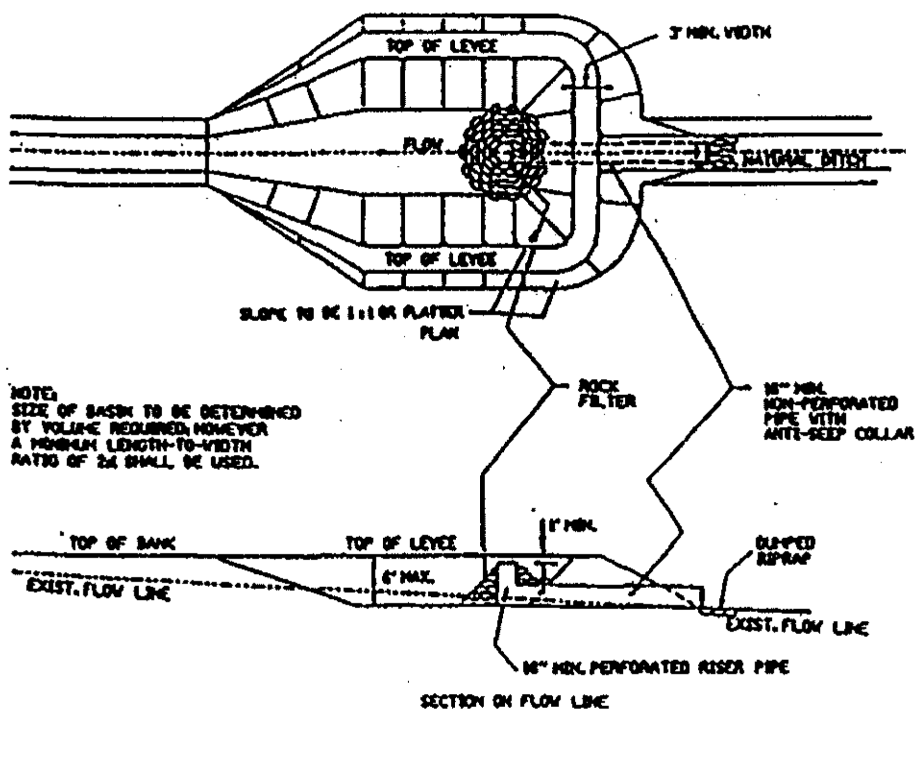
FOR SLOPING AREAS WITH SPARSE VEGETATION

SETTLING BASIN

Figure 7



SEDIMENT BASIN WITH RIPRAP OUTLET



SEDIMENT BASIN WITH PIPE OUTLET

Figure 8

FLEXIBLE DOWNDRAIN

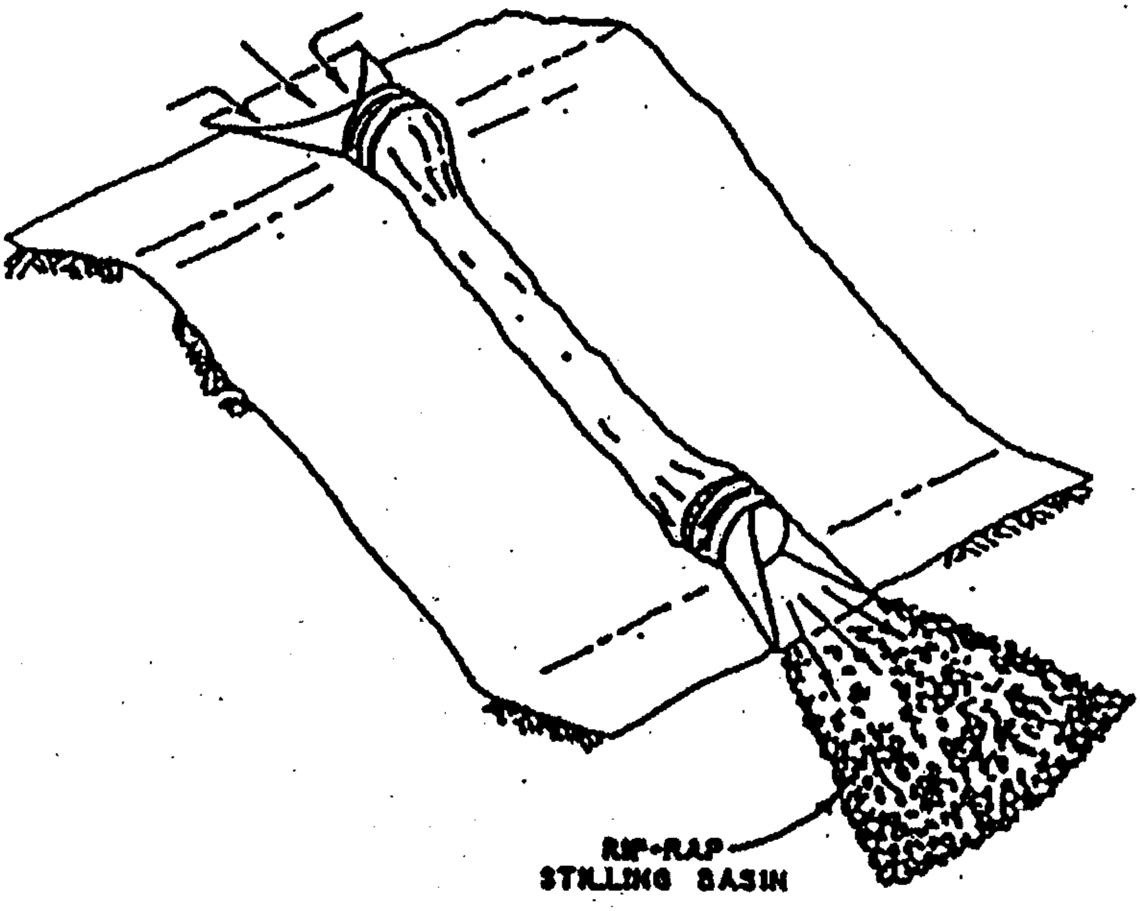


Figure 9

JUTE MATTING INSTALLATION DETAIL

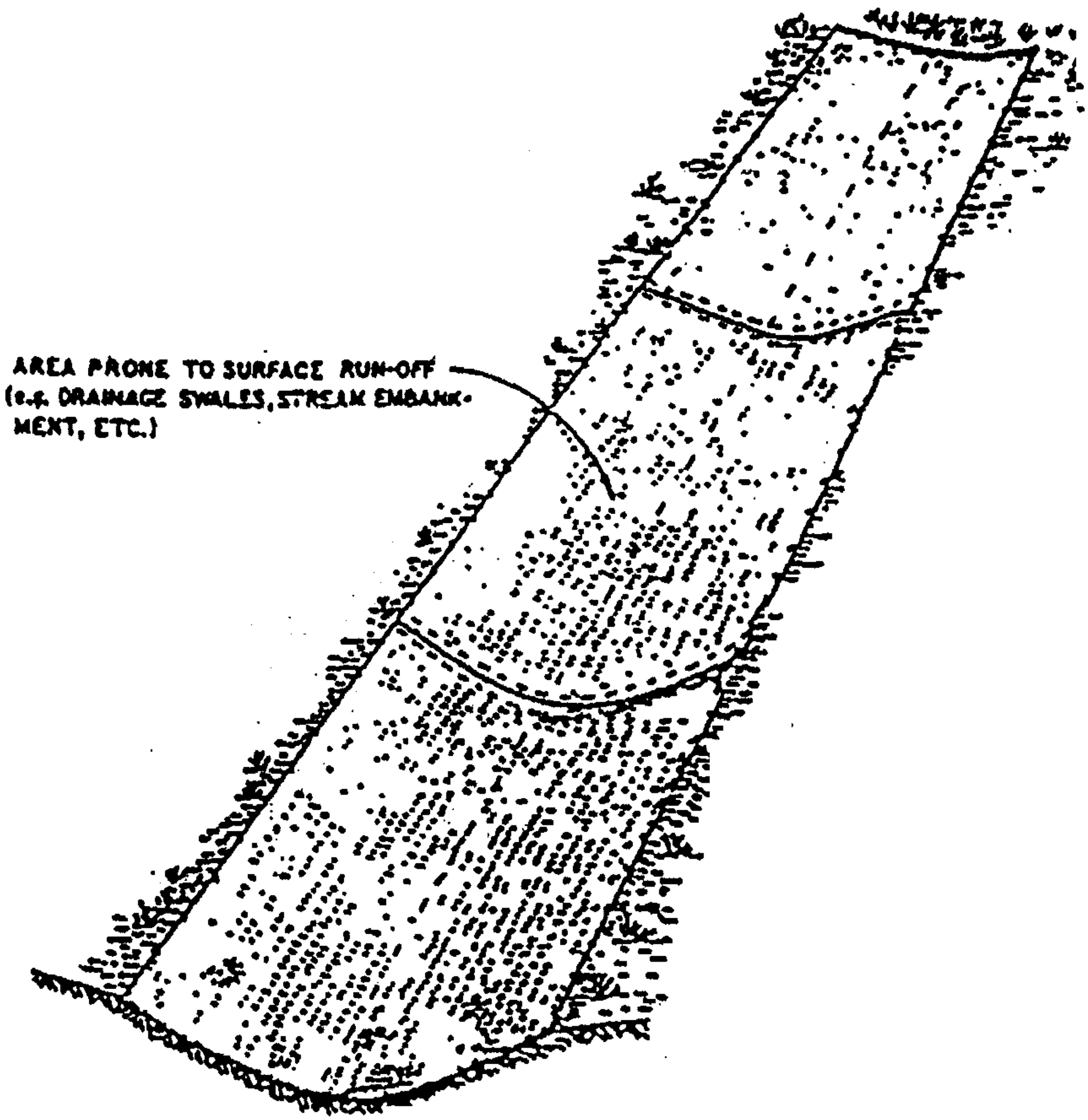


Figure 10

APPENDIX C

FERC PLANS AND PROCEDURES

WETLAND AND WATERBODY CONSTRUCTION AND MITIGATION PROCEDURES

WETLAND AND WATERBODY CONSTRUCTION AND MITIGATION PROCEDURES

TABLE OF CONTENTS

WETLAND AND WATERBODY CONSTRUCTION AND MITIGATION PROCEDURES (PROCEDURES)

I. APPLICABILITY

A. The intent of these Procedures is to assist project sponsors by identifying baseline mitigation measures for minimizing the extent and duration of project-related disturbance on wetlands and waterbodies. Project sponsors shall specify in their applications for a new FERC authorization, and in prior notice and advance notice filings, any individual measures in these Procedures they consider unnecessary, technically infeasible, or unsuitable due to local conditions and fully describe any alternative measures they would use. Project sponsors shall also explain how those alternative measures would achieve a comparable level of mitigation.

Once a project is authorized, project sponsors can request further changes as variances to the measures in these Procedures (or the applicant's approved procedures). The Director of the Office of Energy Projects (Director) will consider approval of variances upon the project sponsor's written request, if the Director agrees that a variance:

1. provides equal or better environmental protection;

2. is necessary because a portion of these Procedures is infeasible or unworkable based on project-specific conditions; or

3. is specifically required in writing by another federal, state, or Native American land management agency for the portion of the project on its land or under its jurisdiction.

Sponsors of projects planned for construction under the automatic authorization provisions in the FERC's regulations must receive written approval for any variances in advance of construction.

Project-related impacts on non-wetland areas are addressed in the staff's Upland Erosion Control, Revegetation, and Maintenance Plan (Plan).

B. DEFINITIONS

1. "Waterbody" includes any natural or artificial stream, river, or drainage with perceptible flow at the time of crossing, and other permanent waterbodies such as ponds and lakes:

   a. "minor waterbody" includes all waterbodies less than or equal to 10 feet wide at the water's edge at the time of crossing;

   b. "intermediate waterbody" includes all waterbodies greater than 10 feet wide but less than or equal to 100 feet wide at the water's edge at the time of crossing; and

   c. "major waterbody" includes all waterbodies greater than 100 feet wide at the water's edge at the time of crossing.

2. "Wetland" includes any area that is not in actively cultivated or rotated cropland and that satisfies the requirements of the current federal methodology for identifying and delineating wetlands.

II. PRECONSTRUCTION FILING

A. The following information must be filed with the Secretary of the FERC (Secretary) prior to the beginning of construction, for the review and written approval by the Director:

1. site-specific justifications for extra work areas that would be closer than 50 feet from a waterbody or wetland; and

2. site-specific justifications for the use of a construction right-of-way greater than 75-feet-wide in wetlands.

B. The following information must be filed with the Secretary prior to the beginning of construction. These filing requirements do not apply to projects constructed under the automatic authorization provisions in the FERC's regulations:

1. Spill Prevention and Response Procedures specified in section IV.A;

2. a schedule identifying when trenching or blasting will occur within each waterbody greater than 10 feet wide, within any designated coldwater fishery, and within any waterbody identified as habitat for federally-listed threatened or endangered species. The project sponsor will revise the schedule as necessary to provide FERC staff at least 14 days advance notice. Changes within this last 14-day period must provide for at least 48 hours advance notice;

3. plans for horizontal directional drills (HDD) under wetlands or waterbodies, specified in section V.B.6.d;

4. site-specific plans for major waterbody crossings, described in section V.B.9;

5. a wetland delineation report as described in section VI.A.1, if applicable; and

6. the hydrostatic testing information specified in section VII.B.3.

III. ENVIRONMENTAL INSPECTORS

A. At least one Environmental Inspector having knowledge of the wetland and waterbody conditions in the project area is required for each construction spread. The number and experience of Environmental Inspectors assigned to each construction spread shall be appropriate for the length of the construction spread and the number/significance of resources affected.

B. The Environmental Inspector's responsibilities are outlined in the Upland Erosion Control, Revegetation, and Maintenance Plan (Plan).

IV. PRECONSTRUCTION PLANNING

A. The project sponsor shall develop project-specific Spill Prevention and Response Procedures that meet applicable requirements of state and federal agencies. A copy must be filed with the Secretary prior to construction and made available in the field on each construction spread. This filing requirement does not apply to projects constructed under the automatic authorization provisions in the FERC's regulations.

1. It shall be the responsibility of the project sponsor and its contractors to structure their operations in a manner that reduces the risk of spills or the accidental exposure of fuels or hazardous materials to waterbodies or wetlands. The project sponsor and its contractors must, at a minimum, ensure that:

a. all employees handling fuels and other hazardous materials are properly trained;

b. all equipment is in good operating order and inspected on a regular basis;

c. fuel trucks transporting fuel to on-site equipment travel only on approved access roads;

d. all equipment is parked overnight and/or fueled at least 100 feet from a waterbody or in an upland area at least 100 feet from a wetland boundary. These activities can occur closer only if the Environmental Inspector determines that there is no reasonable alternative, and the project sponsor and its contractors have taken appropriate steps (including secondary containment structures) to prevent spills and provide for prompt cleanup in the event of a spill;

e. hazardous materials, including chemicals, fuels, and lubricating oils, are not stored within 100 feet of a wetland, waterbody, or designated municipal watershed area, unless the location is designated for such use by an appropriate governmental authority. This applies to storage of these materials and does not apply to normal operation or use of equipment in these areas;

f. concrete coating activities are not performed within 100 feet of a wetland or waterbody boundary, unless the location is an existing industrial site designated for such use. These activities can occur closer only if the Environmental Inspector determines that there is no reasonable alternative, and the project sponsor and its contractors have taken appropriate steps (including secondary containment structures) to prevent spills and provide for prompt cleanup in the event of a spill;

g. pumps operating within 100 feet of a waterbody or wetland boundary utilize appropriate secondary containment systems to prevent spills; and

h. bulk storage of hazardous materials, including chemicals, fuels, and lubricating oils have appropriate secondary containment systems to prevent spills.

2. The project sponsor and its contractors must structure their operations in a manner that provides for the prompt and effective cleanup of spills of fuel and other hazardous materials. At a minimum, the project sponsor and its contractors must:

a. ensure that each construction crew (including cleanup crews) has on hand sufficient supplies of absorbent and barrier materials to allow the rapid containment and recovery of spilled materials and knows the procedure for reporting spills and unanticipated discoveries of contamination;

b. ensure that each construction crew has on hand sufficient tools and material to stop leaks;

c. know the contact names and telephone numbers for all local, state, and federal agencies (including, if necessary, the U. S. Coast Guard and the National Response Center) that must be notified of a spill; and

d. follow the requirements of those agencies in cleaning up the spill, in excavating and disposing of soils or other materials contaminated by a spill, and in collecting and disposing of waste generated during spill cleanup.

B. AGENCY COORDINATION

The project sponsor must coordinate with the appropriate local, state, and federal agencies as outlined in these Procedures and in the FERC's Orders.

V. WATERBODY CROSSINGS

A. NOTIFICATION PROCEDURES AND PERMITS

1. Apply to the U.S. Army Corps of Engineers (COE), or its delegated agency, for the appropriate wetland and waterbody crossing permits.

2. Provide written notification to authorities responsible for potable surface water supply intakes located within 3 miles downstream of the crossing at least 1 week before beginning work in the waterbody, or as otherwise specified by that authority.

3. Apply for state-issued waterbody crossing permits and obtain individual or generic section 401 water quality certification or waiver.

4. Notify appropriate federal and state authorities at least 48 hours before beginning trenching or blasting within the waterbody, or as specified in applicable permits.

B. INSTALLATION

1. Time Window for Construction

Unless expressly permitted or further restricted by the appropriate federal or state agency in writing on a site-specific basis, instream work, except that required to install or remove equipment bridges, must occur during the following time windows:

a. coldwater fisheries - June 1 through September 30; and

b. coolwater and warmwater fisheries - June 1 through November 30.

2. Extra Work Areas

a. Locate all extra work areas (such as staging areas and additional spoil storage areas) at least 50 feet away from water's edge, except where the adjacent upland consists of cultivated or rotated cropland or other disturbed land.

b. The project sponsor shall file with the Secretary for review and written approval by the Director, site-specific justification for each extra work area with a less than 50-foot setback from the water's edge, except where the adjacent upland consists of cultivated or rotated cropland or other disturbed land. The justification must specify the conditions that will not permit a 50-foot setback and measures to ensure the waterbody is adequately protected.

c. Limit the size of extra work areas to the minimum needed to construct the waterbody crossing.

3. General Crossing Procedures

a. Comply with the COE, or its delegated agency, permit terms and conditions.

b. Construct crossings as close to perpendicular to the axis of the waterbody channel as engineering and routing conditions permit.

c. Where pipelines parallel a waterbody, maintain at least 15 feet of undisturbed vegetation between the waterbody (and any adjacent wetland) and the construction right-of-way, except where maintaining this offset will result in greater environmental impact.

d. Where waterbodies meander or have multiple channels, route the pipeline to minimize the number of waterbody crossings.

e. Maintain adequate waterbody flow rates to protect aquatic life, and prevent the interruption of existing downstream uses.

f. Waterbody buffers (e.g., extra work area setbacks, refueling restrictions) must be clearly marked in the field with signs and/or highly visible flagging until construction-related ground disturbing activities are complete.

g. Crossing of waterbodies when they are dry or frozen and not flowing may proceed using standard upland construction techniques in accordance with the Plan, provided that the Environmental Inspector verifies that water is unlikely to flow between initial disturbance and final stabilization of the feature. In the event of perceptible flow, the project sponsor must comply with all applicable Procedure requirements for "waterbodies" as defined in section I.B.1.

4. Spoil Pile Placement and Control

   a. All spoil from minor and intermediate waterbody crossings, and upland spoil from major waterbody crossings, must be placed in the construction right-of-way at least 10 feet from the water's edge or in additional extra work areas as described in section V.B.2.

   b. Use sediment barriers to prevent the flow of spoil or silt-laden water into any waterbody.

5. Equipment Bridges

   a. Only clearing equipment and equipment necessary for installation of equipment bridges may cross waterbodies prior to bridge installation. Limit the number of such crossings of each waterbody to one per piece of clearing equipment.

   b. Construct and maintain equipment bridges to allow unrestricted flow and to prevent soil from entering the waterbody. Examples of such bridges include:

      (1) equipment pads and culvert(s);
      (2) equipment pads or railroad car bridges without culverts;
      (3) clean rock fill and culvert(s); and
      (4) flexi-float or portable bridges.

      Additional options for equipment bridges may be utilized that achieve the performance objectives noted above. Do not use soil to construct or stabilize equipment bridges.

   c. Design and maintain each equipment bridge to withstand and pass the highest flow expected to occur while the bridge is in place. Align culverts to prevent bank erosion or streambed scour. If necessary, install energy dissipating devices downstream of the culverts.

   d. Design and maintain equipment bridges to prevent soil from entering the waterbody.

   e. Remove temporary equipment bridges as soon as practicable after permanent seeding.

   f. If there will be more than 1 month between final cleanup and the beginning of permanent seeding and reasonable alternative access to the right-of-way is available, remove temporary equipment bridges as soon as practicable after final cleanup.

g. Obtain any necessary approval from the COE, or the appropriate state agency for permanent bridges.

6. Dry-Ditch Crossing Methods

a. Unless approved otherwise by the appropriate federal or state agency, install the pipeline using one of the dry-ditch methods outlined below for crossings of waterbodies up to 30 feet wide (at the water's edge at the time of construction) that are state-designated as either coldwater or significant coolwater or warmwater fisheries, or federally-designated as critical habitat.

b. Dam and Pump

(1) The dam-and-pump method may be used without prior approval for crossings of waterbodies where pumps can adequately transfer streamflow volumes around the work area, and there are no concerns about sensitive species passage.

(2) Implementation of the dam-and-pump crossing method must meet the following performance criteria:

(i) use sufficient pumps, including on-site backup pumps, to maintain downstream flows;
(ii) construct dams with materials that prevent sediment and other pollutants from entering the waterbody (e.g., sandbags or clean gravel with plastic liner);
(iii) screen pump intakes to minimize entrainment of fish;
(iv) prevent streambed scour at pump discharge; and
(v) continuously monitor the dam and pumps to ensure proper operation throughout the waterbody crossing.

c. Flume Crossing

The flume crossing method requires implementation of the following steps:

(1) install flume pipe after blasting (if necessary), but before any trenching;

(2) use sand bag or sand bag and plastic sheeting diversion structure or equivalent to develop an effective seal and to divert stream flow through the flume pipe (some modifications to the stream bottom may be required to achieve an effective seal);

(3) properly align flume pipe(s) to prevent bank erosion and streambed scour;

(4) do not remove flume pipe during trenching, pipelaying, or backfilling activities, or initial streambed restoration efforts; and

(5) remove all flume pipes and dams that are not also part of the equipment bridge as soon as final cleanup of the stream bed and bank is complete.

d. Horizontal Directional Drill

For each waterbody or wetland that would be crossed using the HDD method, file with the Secretary for the review and written approval by the Director, a plan that includes:

(1) site-specific construction diagrams that show the location of mud pits, pipe assembly areas, and all areas to be disturbed or cleared for construction;

(2) justification that disturbed areas are limited to the minimum needed to construct the crossing;

(3) identification of any aboveground disturbance or clearing between the HDD entry and exit workspaces during construction;

(4) a description of how an inadvertent release of drilling mud would be contained and cleaned up; and

(5) a contingency plan for crossing the waterbody or wetland in the event the HDD is unsuccessful and how the abandoned drill hole would be sealed, if necessary.

The requirement to file HDD plans does not apply to projects constructed under the automatic authorization provisions in the FERC's regulations.

7. Crossings of Minor Waterbodies

Where a dry-ditch crossing is not required, minor waterbodies may be crossed using the open-cut crossing method, with the following restrictions:

a. except for blasting and other rock breaking measures, complete instream construction activities (including trenching, pipe installation, backfill, and restoration of the streambed contours) within 24 hours.

Streambanks and unconsolidated streambeds may require additional restoration after this period;

b. limit use of equipment operating in the waterbody to that needed to construct the crossing; and

c. equipment bridges are not required at minor waterbodies that do not have a state-designated fishery classification or protected status (e.g., agricultural or intermittent drainage ditches). However, if an equipment bridge is used it must be constructed as described in section V.B.5.

8. Crossings of Intermediate Waterbodies

Where a dry-ditch crossing is not required, intermediate waterbodies may be crossed using the open-cut crossing method, with the following restrictions:

a. complete instream construction activities (not including blasting and other rock breaking measures) within 48 hours, unless site-specific conditions make completion within 48 hours infeasible;

b. limit use of equipment operating in the waterbody to that needed to construct the crossing; and

c. all other construction equipment must cross on an equipment bridge as specified in section V.B.5.

9. Crossings of Major Waterbodies

Before construction, the project sponsor shall file with the Secretary for the review and written approval by the Director a detailed, site-specific construction plan and scaled drawings identifying all areas to be disturbed by construction for each major waterbody crossing (the scaled drawings are not required for any offshore portions of pipeline projects). This plan must be developed in consultation with the appropriate state and federal agencies and shall include extra work areas, spoil storage areas, sediment control structures, etc., as well as mitigation for navigational issues. The requirement to file major waterbody crossing plans does not apply to projects constructed under the automatic authorization provisions of the FERC's regulations.

The Environmental Inspector may adjust the final placement of the erosion and sediment control structures in the field to maximize effectiveness.

10. Temporary Erosion and Sediment Control

Install sediment barriers (as defined in section IV.F.3.a of the Plan) immediately after initial disturbance of the waterbody or adjacent upland.

Sediment barriers must be properly maintained throughout construction and reinstalled as necessary (such as after backfilling of the trench) until replaced by permanent erosion controls or restoration of adjacent upland areas is complete. Temporary erosion and sediment control measures are addressed in more detail in the Plan; however, the following specific measures must be implemented at stream crossings:

a. install sediment barriers across the entire construction right-of-way at all waterbody crossings, where necessary to prevent the flow of sediments into the waterbody. Removable sediment barriers (or driveable berms) must be installed across the travel lane. These removable sediment barriers can be removed during the construction day, but must be re-installed after construction has stopped for the day and/or when heavy precipitation is imminent;

b. where waterbodies are adjacent to the construction right-of-way and the right-of-way slopes toward the waterbody, install sediment barriers along the edge of the construction right-of-way as necessary to contain spoil within the construction right-of-way and prevent sediment flow into the waterbody; and

c. use temporary trench plugs at all waterbody crossings, as necessary, to prevent diversion of water into upland portions of the pipeline trench and to keep any accumulated trench water out of the waterbody.

11. Trench Dewatering

Dewater the trench (either on or off the construction right-of-way) in a manner that does not cause erosion and does not result in silt-laden water flowing into any waterbody. Remove the dewatering structures as soon as practicable after the completion of dewatering activities.

C. RESTORATION

1. Use clean gravel or native cobbles for the upper 1 foot of trench backfill in all waterbodies that contain coldwater fisheries.

2. For open-cut crossings, stabilize waterbody banks and install temporary sediment barriers within 24 hours of completing instream construction activities. For dry-ditch crossings, complete streambed and bank stabilization before returning flow to the waterbody channel.

3. Return all waterbody banks to preconstruction contours or to a stable angle of repose as approved by the Environmental Inspector.

4. Install erosion control fabric or a functional equivalent on waterbody banks at the time of final bank recontouring. Do not use synthetic monofilament

mesh/netted erosion control materials in areas designated as sensitive wildlife habitat unless the product is specifically designed to minimize harm to wildlife. Anchor erosion control fabric with staples or other appropriate devices.

5. Application of riprap for bank stabilization must comply with COE, or its delegated agency, permit terms and conditions.

6. Unless otherwise specified by state permit, limit the use of riprap to areas where flow conditions preclude effective vegetative stabilization techniques such as seeding and erosion control fabric.

7. Revegetate disturbed riparian areas with native species of conservation grasses, legumes, and woody species, similar in density to adjacent undisturbed lands.

8. Install a permanent slope breaker across the construction right-of-way at the base of slopes greater than 5 percent that are less than 50 feet from the waterbody, or as needed to prevent sediment transport into the waterbody. In addition, install sediment barriers as outlined in the Plan.

   In some areas, with the approval of the Environmental Inspector, an earthen berm may be suitable as a sediment barrier adjacent to the waterbody.

9. Sections V.C.3 through V.C.7 above also apply to those perennial or intermittent streams not flowing at the time of construction.

D. POST-CONSTRUCTION MAINTENANCE

1. Limit routine vegetation mowing or clearing adjacent to waterbodies to allow a riparian strip at least 25 feet wide, as measured from the waterbody's mean high water mark, to permanently revegetate with native plant species across the entire construction right-of-way. However, to facilitate periodic corrosion/leak surveys, a corridor centered on the pipeline and up to 10 feet wide may be cleared at a frequency necessary to maintain the 10-foot corridor in an herbaceous state. In addition, trees that are located within 15 feet of the pipeline that have roots that could compromise the integrity of the pipeline coating may be cut and removed from the permanent right-of-way. Do not conduct any routine vegetation mowing or clearing in riparian areas that are between HDD entry and exit points.

2. Do not use herbicides or pesticides in or within 100 feet of a waterbody except as allowed by the appropriate land management or state agency.

3. Time of year restrictions specified in section VII.A.5 of the Plan (April 15 – August 1 of any year) apply to routine mowing and clearing of riparian areas.

VI. WETLAND CROSSINGS

A. GENERAL

1. The project sponsor shall conduct a wetland delineation using the current federal methodology and file a wetland delineation report with the Secretary before construction. The requirement to file a wetland delineation report does not apply to projects constructed under the automatic authorization provisions in the FERC's regulations.

   This report shall identify:

   a. by milepost all wetlands that would be affected;

   b. the National Wetlands Inventory (NWI) classification for each wetland;

   c. the crossing length of each wetland in feet; and

   d. the area of permanent and temporary disturbance that would occur in each wetland by NWI classification type.

   The requirements outlined in this section do not apply to wetlands in actively cultivated or rotated cropland. Standard upland protective measures, including workspace and topsoiling requirements, apply to these agricultural wetlands.

2. Route the pipeline to avoid wetland areas to the maximum extent possible. If a wetland cannot be avoided or crossed by following an existing right-of-way, route the new pipeline in a manner that minimizes disturbance to wetlands. Where looping an existing pipeline, overlap the existing pipeline right-of-way with the new construction right-of-way. In addition, locate the loop line no more than 25 feet away from the existing pipeline unless site-specific constraints would adversely affect the stability of the existing pipeline.

3. Limit the width of the construction right-of-way to 75 feet or less. Prior written approval of the Director is required where topographic conditions or soil limitations require that the construction right-of-way width within the boundaries of a federally delineated wetland be expanded beyond 75 feet. Early in the planning process the project sponsor is encouraged to identify site-specific areas where excessively wide trenches could occur and/or where spoil piles could be difficult to maintain because existing soils lack adequate unconfined compressive strength.

4. Wetland boundaries and buffers must be clearly marked in the field with signs and/or highly visible flagging until construction-related ground disturbing activities are complete.

5. Implement the measures of sections V <u>and</u> VI in the event a waterbody crossing is located within or adjacent to a wetland crossing. If all measures of sections V and VI cannot be met, the project sponsor must file with the Secretary a site-specific crossing plan for review and written approval by the Director before construction. This crossing plan shall address at a minimum:

   a. spoil control;

   b. equipment bridges;

   c. restoration of waterbody banks and wetland hydrology;

   d. timing of the waterbody crossing;

   e. method of crossing; and

   f. size and location of all extra work areas.

6. Do not locate aboveground facilities in any wetland, except where the location of such facilities outside of wetlands would prohibit compliance with U.S. Department of Transportation regulations.

B. INSTALLATION

1. Extra Work Areas and Access Roads

   a. Locate all extra work areas (such as staging areas and additional spoil storage areas) at least 50 feet away from wetland boundaries, except where the adjacent upland consists of cultivated or rotated cropland or other disturbed land.

   b. The project sponsor shall file with the Secretary for review and written approval by the Director, site-specific justification for each extra work area with a less than 50-foot setback from wetland boundaries, except where adjacent upland consists of cultivated or rotated cropland or other disturbed land. The justification must specify the site-specific conditions that will not permit a 50-foot setback and measures to ensure the wetland is adequately protected.

   c. The construction right-of-way may be used for access when the wetland soil is firm enough to avoid rutting or the construction right-of-way has been appropriately stabilized to avoid rutting (e.g., with timber riprap, prefabricated equipment mats, or terra mats).

   In wetlands that cannot be appropriately stabilized, all construction equipment other than that needed to install the wetland crossing shall use access roads located in upland areas. Where access roads in upland areas do not provide reasonable access, limit all other construction equipment to one pass through the wetland using the construction right-of-way.

d. The only access roads, other than the construction right-of-way, that can be used in wetlands are those existing roads that can be used with no modifications or improvements, other than routine repair, and no impact on the wetland.

2. Crossing Procedures

a. Comply with COE, or its delegated agency, permit terms and conditions.

b. Assemble the pipeline in an upland area unless the wetland is dry enough to adequately support skids and pipe.

c. Use “push-pull” or “float” techniques to place the pipe in the trench where water and other site conditions allow.

d. Minimize the length of time that topsoil is segregated and the trench is open. Do not trench the wetland until the pipeline is assembled and ready for lowering in.

e. Limit construction equipment operating in wetland areas to that needed to clear the construction right-of-way, dig the trench, fabricate and install the pipeline, backfill the trench, and restore the construction right-of-way.

f. Cut vegetation just above ground level, leaving existing root systems in place, and remove it from the wetland for disposal.

The project sponsor can burn woody debris in wetlands, if approved by the COE and in accordance with state and local regulations, ensuring that all remaining woody debris is removed for disposal.

g. Limit pulling of tree stumps and grading activities to directly over the trenchline. Do not grade or remove stumps or root systems from the rest of the construction right-of-way in wetlands unless the Chief Inspector and Environmental Inspector determine that safety-related construction constraints require grading or the removal of tree stumps from under the working side of the construction right-of-way.

h. Segregate the top 1 foot of topsoil from the area disturbed by trenching, except in areas where standing water is present or soils are saturated. Immediately after backfilling is complete, restore the segregated topsoil to its original location.

i. Do not use rock, soil imported from outside the wetland, tree stumps, or brush riprap to support equipment on the construction right-of-way.

j. If standing water or saturated soils are present, or if construction equipment causes ruts or mixing of the topsoil and subsoil in wetlands, use low-ground-weight construction equipment, or operate normal equipment on timber riprap, prefabricated equipment mats, or terra mats.

k. Remove all project-related material used to support equipment on the construction right-of-way upon completion of construction.

3. Temporary Sediment Control

Install sediment barriers (as defined in section IV.F.3.a of the Plan) immediately after initial disturbance of the wetland or adjacent upland. Sediment barriers must be properly maintained throughout construction and reinstalled as necessary (such as after backfilling of the trench). Except as noted below in section VI.B.3.c, maintain sediment barriers until replaced by permanent erosion controls or restoration of adjacent upland areas is complete. Temporary erosion and sediment control measures are addressed in more detail in the Plan.

a. Install sediment barriers across the entire construction right-of-way immediately upslope of the wetland boundary at all wetland crossings where necessary to prevent sediment flow into the wetland.

b. Where wetlands are adjacent to the construction right-of-way and the right-of-way slopes toward the wetland, install sediment barriers along the edge of the construction right-of-way as necessary to contain spoil within the construction right-of-way and prevent sediment flow into the wetland.

c. Install sediment barriers along the edge of the construction right-of-way as necessary to contain spoil and sediment within the construction right-of-way through wetlands. Remove these sediment barriers during right-of-way cleanup.

4. Trench Dewatering

Dewater the trench (either on or off the construction right-of-way) in a manner that does not cause erosion and does not result in silt-laden water flowing into any wetland. Remove the dewatering structures as soon as practicable after the completion of dewatering activities.

C. RESTORATION

1. Where the pipeline trench may drain a wetland, construct trench breakers at the wetland boundaries and/or seal the trench bottom as necessary to maintain the original wetland hydrology.

2. Restore pre-construction wetland contours to maintain the original wetland hydrology.

3. For each wetland crossed, install a trench breaker at the base of slopes near the boundary between the wetland and adjacent upland areas. Install a permanent slope breaker across the construction right-of-way at the base of slopes greater than 5 percent where the base of the slope is less than 50 feet from the wetland, or as needed to prevent sediment transport into the wetland. In addition, install sediment barriers as outlined in the Plan. In some areas, with the approval of the Environmental Inspector, an earthen berm may be suitable as a sediment barrier adjacent to the wetland.

4. Do not use fertilizer, lime, or mulch unless required in writing by the appropriate federal or state agency.

5. Consult with the appropriate federal or state agencies to develop a project-specific wetland restoration plan. The restoration plan shall include measures for re-establishing herbaceous and/or woody species, controlling the invasion and spread of invasive species and noxious weeds (e.g., purple loosestrife and phragmites), and monitoring the success of the revegetation and weed control efforts. Provide this plan to the FERC staff upon request.

6. Until a project-specific wetland restoration plan is developed and/or implemented, temporarily revegetate the construction right-of-way with annual ryegrass at a rate of 40 pounds/acre (unless standing water is present).

7. Ensure that all disturbed areas successfully revegetate with wetland herbaceous and/or woody plant species.

8. Remove temporary sediment barriers located at the boundary between wetland and adjacent upland areas after revegetation and stabilization of adjacent upland areas are judged to be successful as specified in section VII.A.4 of the Plan.

D. POST-CONSTRUCTION MAINTENANCE AND REPORTING

1. Do not conduct routine vegetation mowing or clearing over the full width of the permanent right-of-way in wetlands. However, to facilitate periodic corrosion/leak surveys, a corridor centered on the pipeline and up to 10 feet wide may be cleared at a frequency necessary to maintain the 10-foot corridor in an herbaceous state. In addition, trees within 15 feet of the pipeline with roots that could compromise the integrity of pipeline coating may be selectively cut and removed from the permanent right-of-way. Do not conduct any routine vegetation mowing or clearing in wetlands that are between HDD entry and exit points.

2. Do not use herbicides or pesticides in or within 100 feet of a wetland, except as allowed by the appropriate federal or state agency.

3. Time of year restrictions specified in section VII.A.5 of the Plan (April 15 – August 1 of any year) apply to routine mowing and clearing of wetland areas.

4. Monitor and record the success of wetland revegetation annually until wetland revegetation is successful.

5. Wetland revegetation shall be considered successful if all of the following criteria are satisfied:

   a. the affected wetland satisfies the current federal definition for a wetland (i.e., soils, hydrology, and vegetation);

   b. vegetation is at least 80 percent of either the cover documented for the wetland prior to construction, or at least 80 percent of the cover in adjacent wetland areas that were not disturbed by construction;

   c. if natural rather than active revegetation was used, the plant species composition is consistent with early successional wetland plant communities in the affected ecoregion; and

   d. invasive species and noxious weeds are absent, unless they are abundant in adjacent areas that were not disturbed by construction.

6. Within 3 years after construction, file a report with the Secretary identifying the status of the wetland revegetation efforts and documenting success as defined in section VI.D.5, above. The requirement to file wetland restoration reports with the Secretary does not apply to projects constructed under the automatic authorization, prior notice, or advance notice provisions in the FERC's regulations.

   For any wetland where revegetation is not successful at the end of 3 years after construction, develop and implement (in consultation with a professional wetland ecologist) a remedial revegetation plan to actively revegetate wetlands. Continue revegetation efforts and file a report annually documenting progress in these wetlands until wetland revegetation is successful.

VII. HYDROSTATIC TESTING

A. NOTIFICATION PROCEDURES AND PERMITS

1. Apply for state-issued water withdrawal permits, as required.

2. Apply for National Pollutant Discharge Elimination System (NPDES) or state-issued discharge permits, as required.

3. Notify appropriate state agencies of intent to use specific sources at least 48 hours before testing activities unless they waive this requirement in writing.

B. GENERAL

1. Perform 100 percent radiographic inspection of all pipeline section welds or hydrotest the pipeline sections, before installation under waterbodies or wetlands.

2. If pumps used for hydrostatic testing are within 100 feet of any waterbody or wetland, address secondary containment and refueling of these pumps in the project's Spill Prevention and Response Procedures.

3. The project sponsor shall file with the Secretary before construction a list identifying the location of all waterbodies proposed for use as a hydrostatic test water source or discharge location. This filing requirement does not apply to projects constructed under the automatic authorization provisions of the FERC's regulations.

C. INTAKE SOURCE AND RATE

1. Screen the intake hose to minimize the potential for entrainment of fish.

2. Do not use state-designated exceptional value waters, waterbodies which provide habitat for federally listed threatened or endangered species, or waterbodies designated as public water supplies, unless appropriate federal, state, and/or local permitting agencies grant written permission.

3. Maintain adequate flow rates to protect aquatic life, provide for all waterbody uses, and provide for downstream withdrawals of water by existing users.

4. Locate hydrostatic test manifolds outside wetlands and riparian areas to the maximum extent practicable.

D. DISCHARGE LOCATION, METHOD, AND RATE

1. Regulate discharge rate, use energy dissipation device(s), and install sediment barriers, as necessary, to prevent erosion, streambed scour, suspension of sediments, or excessive streamflow.

2. Do not discharge into state-designated exceptional value waters, waterbodies which provide habitat for federally listed threatened or endangered species, or waterbodies designated as public water supplies, unless appropriate federal, state, and local permitting agencies grant written permission.

UPLAND EROSION CONTROL, REVEGETATION, AND MAINTENANCE PLAN

MAY 2013 VERSION

UPLAND EROSION CONTROL, REVEGETATION, AND MAINTENANCE PLAN

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UPLAND EROSION CONTROL, REVEGETATION, AND MAINTENANCE PLAN (PLAN)

I. APPLICABILITY

A. The intent of this Plan is to assist project sponsors by identifying baseline mitigation measures for minimizing erosion and enhancing revegetation. Project sponsors shall specify in their applications for a new FERC authorization and in prior notice and advance notice filings, any individual measures in this Plan they consider unnecessary, technically infeasible, or unsuitable due to local conditions and fully describe any alternative measures they would use. Project sponsors shall also explain how those alternative measures would achieve a comparable level of mitigation.

Once a project is authorized, project sponsors can request further changes as variances to the measures in this Plan (or the applicant's approved plan). The Director of the Office of Energy Projects (Director) will consider approval of variances upon the project sponsor's written request, if the Director agrees that a variance:

1. provides equal or better environmental protection;

2. is necessary because a portion of this Plan is infeasible or unworkable based on project-specific conditions; or

3. is specifically required in writing by another federal, state, or Native American land management agency for the portion of the project on its land or under its jurisdiction.

Sponsors of projects planned for construction under the automatic authorization provisions in the FERC's regulations must receive written approval for any variances in advance of construction.

Project-related impacts on wetland and waterbody systems are addressed in the staff's Wetland and Waterbody Construction and Mitigation Procedures (Procedures).

II. SUPERVISION AND INSPECTION

A. ENVIRONMENTAL INSPECTION

1. At least one Environmental Inspector is required for each construction spread during construction and restoration (as defined by section V). The number and experience of Environmental Inspectors assigned to each construction spread shall be appropriate for the length of the construction spread and the number/significance of resources affected.

2. Environmental Inspectors shall have peer status with all other activity inspectors.

3. Environmental Inspectors shall have the authority to stop activities that violate the environmental conditions of the FERC's Orders, stipulations of other environmental permits or approvals, or landowner easement agreements; and to order appropriate corrective action.

B. RESPONSIBILITIES OF ENVIRONMENTAL INSPECTORS

At a minimum, the Environmental Inspector(s) shall be responsible for:

1. Inspecting construction activities for compliance with the requirements of this Plan, the Procedures, the environmental conditions of the FERC's Orders, the mitigation measures proposed by the project sponsor (as approved and/or modified by the Order), other environmental permits and approvals, and environmental requirements in landowner easement agreements.

2. Identifying, documenting, and overseeing corrective actions, as necessary to bring an activity back into compliance;

3. Verifying that the limits of authorized construction work areas and locations of access roads are visibly marked before clearing, and maintained throughout construction;

4. Verifying the location of signs and highly visible flagging marking the boundaries of sensitive resource areas, waterbodies, wetlands, or areas with special requirements along the construction work area;

5. Identifying erosion/sediment control and soil stabilization needs in all areas;

6. Ensuring that the design of slope breakers will not cause erosion or direct water into sensitive environmental resource areas, including cultural resource sites, wetlands, waterbodies, and sensitive species habitats;

7. Verifying that dewatering activities are properly monitored and do not result in the deposition of sand, silt, and/or sediment into sensitive environmental resource areas, including wetlands, waterbodies, cultural resource sites, and sensitive species habitats; stopping dewatering activities if such deposition is occurring and ensuring the design of the discharge is changed to prevent reoccurrence; and verifying that dewatering structures are removed after completion of dewatering activities;

8. Ensuring that subsoil and topsoil are tested in agricultural and residential areas to measure compaction and determine the need for corrective action;

9. Advising the Chief Construction Inspector when environmental conditions (such as wet weather or frozen soils) make it advisable to restrict or delay construction activities to avoid topsoil mixing or excessive compaction;

10. Ensuring restoration of contours and topsoil;

11. Verifying that the soils imported for agricultural or residential use are certified as free of noxious weeds and soil pests, unless otherwise approved by the landowner;

12. Ensuring that erosion control devices are properly installed to prevent sediment flow into sensitive environmental resource areas (e.g., wetlands, waterbodies, cultural resource sites, and sensitive species habitats) and onto roads, and determining the need for additional erosion control devices;

13. Inspecting and ensuring the maintenance of temporary erosion control measures at least:

    a. on a daily basis in areas of active construction or equipment operation;

    b. on a weekly basis in areas with no construction or equipment operation; and

    c. within 24 hours of each 0.5 inch of rainfall;

14. Ensuring the repair of all ineffective temporary erosion control measures within 24 hours of identification, or as soon as conditions allow if compliance with this time frame would result in greater environmental impacts;

15. Keeping records of compliance with the environmental conditions of the FERC's Orders, and the mitigation measures proposed by the project sponsor in the application submitted to the FERC, and other federal or state environmental permits during active construction and restoration;

16. Identifying areas that should be given special attention to ensure stabilization and restoration after the construction phase; and

17. Verifying that locations for any disposal of excess construction materials for beneficial reuse comply with section III.E.

III. PRECONSTRUCTION PLANNING

The project sponsor shall do the following before construction:

A. CONSTRUCTION WORK AREAS

1. Identify all construction work areas (e.g., construction right-of-way, extra work space areas, pipe storage and contractor yards, borrow and disposal areas, access roads) that would be needed for safe construction. The project sponsor must ensure that appropriate cultural resources and biological surveys are conducted, as determined necessary by the appropriate federal and state agencies.

2. Project sponsors are encouraged to consider expanding any required cultural resources and endangered species surveys in anticipation of the need for activities outside of authorized work areas.

3. Plan construction sequencing to limit the amount and duration of open trench sections, as necessary, to prevent excessive erosion or sediment flow into sensitive environmental resource areas.

B. DRAIN TILE AND IRRIGATION SYSTEMS

1. Attempt to locate existing drain tiles and irrigation systems.

2. Contact landowners and local soil conservation authorities to determine the locations of future drain tiles that are likely to be installed within 3 years of the authorized construction.

3. Develop procedures for constructing through drain-tiled areas, maintaining irrigation systems during construction, and repairing drain tiles and irrigation systems after construction.

4. Engage qualified drain tile specialists, as needed to conduct or monitor repairs to drain tile systems affected by construction. Use drain tile specialists from the project area, if available.

C. GRAZING DEFERMENT

Develop grazing deferment plans with willing landowners, grazing permittees, and land management agencies to minimize grazing disturbance of revegetation efforts.

D. ROAD CROSSINGS AND ACCESS POINTS

Plan for safe and accessible conditions at all roadway crossings and access points during construction and restoration.

E. DISPOSAL PLANNING

Determine methods and locations for the regular collection, containment, and disposal of excess construction materials and debris (e.g., timber, slash, mats, garbage, drill cuttings and fluids, excess rock) throughout the construction process. Disposal of materials for beneficial reuse must not result in adverse environmental impact and is subject to compliance with all applicable survey, landowner or land management agency approval, and permit requirements.

F. AGENCY COORDINATION

The project sponsor must coordinate with the appropriate local, state, and federal agencies as outlined in this Plan and/or required by the FERC's Orders.

1. Obtain written recommendations from the local soil conservation authorities or land management agencies regarding permanent erosion control and revegetation specifications.

2. Develop specific procedures in coordination with the appropriate agencies to prevent the introduction or spread of invasive species, noxious weeds, and soil pests resulting from construction and restoration activities.

3. Develop specific procedures in coordination with the appropriate agencies and landowners, as necessary, to allow for livestock and wildlife movement and protection during construction.

4. Develop specific blasting procedures in coordination with the appropriate agencies that address pre- and post-blast inspections; advanced public notification; and mitigation measures for building foundations, groundwater wells, and springs. Use appropriate methods (e.g., blasting mats) to prevent damage to nearby structures and to prevent debris from entering sensitive environmental resource areas.

G. SPILL PREVENTION AND RESPONSE PROCEDURES

The project sponsor shall develop project-specific Spill Prevention and Response Procedures, as specified in section IV of the staff's Procedures. A copy must be filed with the Secretary of the FERC (Secretary) prior to construction and made available in the field on each construction spread. The filing requirement does not apply to projects constructed under the automatic authorization provisions in the FERC's regulations.

H. RESIDENTIAL CONSTRUCTION

For all properties with residences located within 50 feet of construction work areas, project sponsors shall: avoid removal of mature trees and landscaping within the construction work area unless necessary for safe operation of construction equipment, or as specified in landowner agreements; fence the edge of the construction work area for a distance of 100 feet on either side of the residence; and restore all lawn areas and landscaping immediately following clean up operations, or as specified in landowner agreements. If seasonal or other weather conditions prevent compliance with these time frames, maintain and monitor temporary erosion controls (sediment barriers and mulch) until conditions allow completion of restoration.

I. WINTER CONSTRUCTION PLANS

If construction is planned to occur during winter weather conditions, project sponsors shall develop and file a project-specific winter construction plan with the FERC application. This filing requirement does not apply to projects constructed under the automatic authorization provisions of the FERC's regulations.

The plan shall address:

1. winter construction procedures (e.g., snow handling and removal, access road construction and maintenance, soil handling under saturated or frozen conditions, topsoil stripping);

2. stabilization and monitoring procedures if ground conditions will delay restoration until the following spring (e.g., mulching and erosion controls, inspection and reporting, stormwater control during spring thaw conditions); and

3. final restoration procedures (e.g., subsidence and compaction repair, topsoil replacement, seeding).

IV. INSTALLATION

A. APPROVED AREAS OF DISTURBANCE

1. Project-related ground disturbance shall be limited to the construction right-of-way, extra work space areas, pipe storage yards, borrow and disposal areas, access roads, and other areas approved in the FERC's Orders. Any project-related ground disturbing activities outside these areas will require prior Director approval. This requirement does not apply to activities needed to comply with the Plan and Procedures (i.e., slope breakers, energy-dissipating devices, dewatering structures, drain tile system repairs) or minor field realignments and workspace shifts per landowner needs and requirements that do not affect other landowners or sensitive environmental resource areas. All construction or restoration activities outside of authorized areas are subject to all applicable survey and permit requirements, and landowner easement agreements.

2. The construction right-of-way width for a project shall not exceed 75 feet or that described in the FERC application unless otherwise modified by a FERC Order. However, in limited, non-wetland areas, this construction right-of-way width may be expanded by up to 25 feet without Director approval to accommodate full construction right-of-way topsoil segregation and to ensure safe construction where topographic conditions (e.g., side-slopes) or soil limitations require it. Twenty-five feet of extra construction right-of-way width may also be used in limited, non-wetland or non-forested areas for truck turn-arounds where no reasonable alternative access exists.

   Project use of these additional limited areas is subject to landowner or land management agency approval and compliance with all applicable survey and permit requirements. When additional areas are used, each one shall be identified and the need explained in the weekly or biweekly construction reports to the FERC, if required. The following material shall be included in the reports:

   a. the location of each additional area by station number and reference to previously filed alignment sheets, or updated alignment sheets showing the additional areas;

   b. identification of the filing at FERC containing evidence that the additional areas were previously surveyed; and

c. a statement that landowner approval has been obtained and is available in project files.

Prior written approval of the Director is required when the authorized construction right-of-way width would be expanded by more than 25 feet.

B. TOPSOIL SEGREGATION

1. Unless the landowner or land management agency specifically approves otherwise, prevent the mixing of topsoil with subsoil by stripping topsoil from either the full work area or from the trench and subsoil storage area (ditch plus spoil side method) in:

   a. cultivated or rotated croplands, and managed pastures;

   b. residential areas;

   c. hayfields; and

   d. other areas at the landowner's or land managing agency's request.

2. In residential areas, importation of topsoil is an acceptable alternative to topsoil segregation.

3. Where topsoil segregation is required, the project sponsor must:

   a. segregate at least 12 inches of topsoil in deep soils (more than 12 inches of topsoil); and

   b. make every effort to segregate the entire topsoil layer in soils with less than 12 inches of topsoil.

4. Maintain separation of salvaged topsoil and subsoil throughout all construction activities.

5. Segregated topsoil may not be used for padding the pipe, constructing temporary slope breakers or trench plugs, improving or maintaining roads, or as a fill material.

6. Stabilize topsoil piles and minimize loss due to wind and water erosion with use of sediment barriers, mulch, temporary seeding, tackifiers, or functional equivalents, where necessary.

C. DRAIN TILES

1. Mark locations of drain tiles damaged during construction.

2. Probe all drainage tile systems within the area of disturbance to check for damage.

3. Repair damaged drain tiles to their original or better condition. Do not use filter-covered drain tiles unless the local soil conservation authorities and the landowner agree. Use qualified specialists for testing and repairs.

4. For new pipelines in areas where drain tiles exist or are planned, ensure that the depth of cover over the pipeline is sufficient to avoid interference with drain tile systems. For adjacent pipeline loops in agricultural areas, install the new pipeline with at least the same depth of cover as the existing pipeline(s).

D. IRRIGATION

Maintain water flow in crop irrigation systems, unless shutoff is coordinated with affected parties.

E. ROAD CROSSINGS AND ACCESS POINTS

1. Maintain safe and accessible conditions at all road crossings and access points during construction.

2. If crushed stone access pads are used in residential or agricultural areas, place the stone on synthetic fabric to facilitate removal.

3. Minimize the use of tracked equipment on public roadways. Remove any soil or gravel spilled or tracked onto roadways daily or more frequent as necessary to maintain safe road conditions. Repair any damages to roadway surfaces, shoulders, and bar ditches.

F. TEMPORARY EROSION CONTROL

Install temporary erosion controls immediately after initial disturbance of the soil. Temporary erosion controls must be properly maintained throughout construction (on a daily basis) and reinstalled as necessary (such as after backfilling of the trench) until replaced by permanent erosion controls or restoration is complete.

1. Temporary Slope Breakers

   a. Temporary slope breakers are intended to reduce runoff velocity and divert water off the construction right-of-way. Temporary slope breakers may be constructed of materials such as soil, silt fence, staked hay or straw bales, or sand bags.

b. Install temporary slope breakers on all disturbed areas, as necessary to avoid excessive erosion. Temporary slope breakers must be installed on slopes greater than 5 percent where the base of the slope is less than 50 feet from waterbody, wetland, and road crossings at the following spacing (closer spacing shall be used if necessary):

Slope (%)	Spacing (feet)
5 - 15	300
>15 - 30	200
>30	100

c. Direct the outfall of each temporary slope breaker to a stable, well vegetated area or construct an energy-dissipating device at the end of the slope breaker and off the construction right-of-way.

d. Position the outfall of each temporary slope breaker to prevent sediment discharge into wetlands, waterbodies, or other sensitive environmental resource areas.

2. Temporary Trench Plugs

Temporary trench plugs are intended to segment a continuous open trench prior to backfill.

a. Temporary trench plugs may consist of unexcavated portions of the trench, compacted subsoil, sandbags, or some functional equivalent.

b. Position temporary trench plugs, as necessary, to reduce trenchline erosion and minimize the volume and velocity of trench water flow at the base of slopes.

3. Sediment Barriers

Sediment barriers are intended to stop the flow of sediments and to prevent the deposition of sediments beyond approved workspaces or into sensitive resources.

a. Sediment barriers may be constructed of materials such as silt fence, staked hay or straw bales, compacted earth (e.g., driveable berms across travelways), sand bags, or other appropriate materials.

b. At a minimum, install and maintain temporary sediment barriers across the entire construction right-of-way at the base of slopes greater than 5 percent where the base of the slope is less than 50 feet from a waterbody, wetland, or road crossing until revegetation is successful as defined in this Plan. Leave adequate room between the base of the slope and the sediment barrier to accommodate ponding of water and sediment deposition.

c. Where wetlands or waterbodies are adjacent to and downslope of construction work areas, install sediment barriers along the edge of these areas, as necessary to prevent sediment flow into the wetland or waterbody.

4. Mulch

a. Apply mulch on all slopes (except in cultivated cropland) concurrent with or immediately after seeding, where necessary to stabilize the soil surface and to reduce wind and water erosion. Spread mulch uniformly over the area to cover at least 75 percent of the ground surface at a rate of 2 tons/acre of straw or its equivalent, unless the local soil conservation authority, landowner, or land managing agency approves otherwise in writing.

b. Mulch can consist of weed-free straw or hay, wood fiber hydromulch, erosion control fabric, or some functional equivalent.

c. Mulch all disturbed upland areas (except cultivated cropland) <u>before</u> seeding if:

(1) final grading and installation of permanent erosion control measures will not be completed in an area within 20 days after the trench in that area is backfilled (10 days in residential areas), as required in section V.A.1; or

(2) construction or restoration activity is interrupted for extended periods, such as when seeding cannot be completed due to seeding period restrictions.

d. If mulching <u>before</u> seeding, increase mulch application on all slopes within 100 feet of waterbodies and wetlands to a rate of 3 tons/acre of straw or equivalent.

e. If wood chips are used as mulch, do not use more than 1 ton/acre and add the equivalent of 11 lbs/acre available nitrogen (at least 50 percent of which is slow release).

f. Ensure that mulch is adequately anchored to minimize loss due to wind and water.

g. When anchoring with liquid mulch binders, use rates recommended by the manufacturer. Do not use liquid mulch binders within 100 feet of wetlands or waterbodies, except where the product is certified environmentally non-toxic by the appropriate state or federal agency or independent standards-setting organization.

h. Do not use synthetic monofilament mesh/netted erosion control materials in areas designated as sensitive wildlife habitat, unless the product is specifically designed to minimize harm to wildlife. Anchor erosion control fabric with staples or other appropriate devices.

V. RESTORATION

A. CLEANUP

1. Commence cleanup operations immediately following backfill operations. Complete final grading, topsoil replacement, and installation of permanent erosion control structures within 20 days after backfilling the trench (10 days in residential areas). If seasonal or other weather conditions prevent compliance with these time frames, maintain temporary erosion controls (i.e., temporary slope breakers, sediment barriers, and mulch) until conditions allow completion of cleanup.

   If construction or restoration unexpectedly continues into the winter season when conditions could delay successful decompaction, topsoil replacement, or seeding until the following spring, file with the Secretary for the review and written approval of the Director, a winter construction plan (as specified in section III.I). This filing requirement does not apply to projects constructed under the automatic authorization provisions of the FERC's regulations.

2. A travel lane may be left open temporarily to allow access by construction traffic if the temporary erosion control structures are installed as specified in section IV.F. and inspected and maintained as specified in sections II.B.12 through 14. When access is no longer required the travel lane must be removed and the right-of-way restored.

3. Rock excavated from the trench may be used to backfill the trench only to the top of the existing bedrock profile. Rock that is not returned to the trench shall be considered construction debris, unless approved for use as mulch or for some other use on the construction work areas by the landowner or land managing agency.

4. Remove excess rock from at least the top 12 inches of soil in all cultivated or rotated cropland, managed pastures, hayfields, and residential areas, as well as other areas at the landowner's request. The size, density, and distribution of rock on the construction work area shall be similar to adjacent areas not disturbed by construction. The landowner or land management agency may approve other provisions in writing.

5. Grade the construction right-of-way to restore pre-construction contours and leave the soil in the proper condition for planting.

6. Remove construction debris from all construction work areas unless the landowner or land managing agency approves leaving materials onsite for beneficial reuse, stabilization, or habitat restoration.

7. Remove temporary sediment barriers when replaced by permanent erosion control measures or when revegetation is successful.

B. PERMANENT EROSION CONTROL DEVICES

1. Trench Breakers

a. Trench breakers are intended to slow the flow of subsurface water along the trench. Trench breakers may be constructed of materials such as sand bags or polyurethane foam. Do not use topsoil in trench breakers.

b. An engineer or similarly qualified professional shall determine the need for and spacing of trench breakers. Otherwise, trench breakers shall be installed at the same spacing as and upslope of permanent slope breakers.

c. In agricultural fields and residential areas where slope breakers are not typically required, install trench breakers at the same spacing as if permanent slope breakers were required.

d. At a minimum, install a trench breaker at the base of slopes greater than 5 percent where the base of the slope is less than 50 feet from a waterbody or wetland and where needed to avoid draining a waterbody or wetland. Install trench breakers at wetland boundaries, as specified in the Procedures. Do not install trench breakers within a wetland.

2. Permanent Slope Breakers

a. Permanent slope breakers are intended to reduce runoff velocity, divert water off the construction right-of-way, and prevent sediment deposition into sensitive resources. Permanent slope breakers may be constructed of materials such as soil, stone, or some functional equivalent.

b. Construct and maintain permanent slope breakers in all areas, except cultivated areas and lawns, unless requested by the landowner, using spacing recommendations obtained from the local soil conservation authority or land managing agency.

In the absence of written recommendations, use the following spacing unless closer spacing is necessary to avoid excessive erosion on the construction right-of-way:

Slope (%)	Spacing (feet)
5 - 15	300
>15 - 30	200
>30	100

c. Construct slope breakers to divert surface flow to a stable area without causing water to pool or erode behind the breaker. In the absence of a stable area, construct appropriate energy-dissipating devices at the end of the breaker.

d. Slope breakers may extend slightly (about 4 feet) beyond the edge of the construction right-of-way to effectively drain water off the disturbed area. Where slope breakers extend beyond the edge of the construction right-of-way, they are subject to compliance with all applicable survey requirements.

C. SOIL COMPACTION MITIGATION

1. Test topsoil and subsoil for compaction at regular intervals in agricultural and residential areas disturbed by construction activities. Conduct tests on the same soil type under similar moisture conditions in undisturbed areas to approximate preconstruction conditions. Use penetrometers or other appropriate devices to conduct tests.

2. Plow severely compacted agricultural areas with a paraplow or other deep tillage implement. In areas where topsoil has been segregated, plow the subsoil before replacing the segregated topsoil.

If subsequent construction and cleanup activities result in further compaction, conduct additional tilling.

3. Perform appropriate soil compaction mitigation in severely compacted residential areas.

D. REVEGETATION

1. General

a. The project sponsor is responsible for ensuring successful revegetation of soils disturbed by project-related activities, except as noted in section V.D.1.b.

b. Restore all turf, ornamental shrubs, and specialized landscaping in accordance with the landowner's request, or compensate the landowner. Restoration work must be performed by personnel familiar with local horticultural and turf establishment practices.

2. Soil Additives

Fertilize and add soil pH modifiers in accordance with written recommendations obtained from the local soil conservation authority, land management agencies, or landowner. Incorporate recommended soil pH modifier and fertilizer into the top 2 inches of soil as soon as practicable after application.

3. Seeding Requirements

a. Prepare a seedbed in disturbed areas to a depth of 3 to 4 inches using appropriate equipment to provide a firm seedbed. When hydroseeding, scarify the seedbed to facilitate lodging and germination of seed.

b. Seed disturbed areas in accordance with written recommendations for seed mixes, rates, and dates obtained from the local soil conservation authority or the request of the landowner or land management agency. Seeding is not required in cultivated croplands unless requested by the landowner.

c. Perform seeding of permanent vegetation within the recommended seeding dates. If seeding cannot be done within those dates, use appropriate temporary erosion control measures discussed in section IV.F and perform seeding of permanent vegetation at the beginning of the next recommended seeding season. Dormant seeding or temporary seeding of annual species may also be used, if necessary, to establish cover, as approved by the Environmental Inspector. Lawns may be seeded on a schedule established with the landowner.

d. In the absence of written recommendations from the local soil conservation authorities, seed all disturbed soils within 6 working days of final grading, weather and soil conditions permitting, subject to the specifications in section V.D.3.a through V.D.3.c.

e. Base seeding rates on Pure Live Seed. Use seed within 12 months of seed testing.

f. Treat legume seed with an inoculant specific to the species using the manufacturer's recommended rate of inoculant appropriate for the seeding method (broadcast, drill, or hydro).

g. In the absence of written recommendations from the local soil conservation authorities, landowner, or land managing agency to the contrary, a seed drill equipped with a cultipacker is preferred for seed application.

Broadcast or hydroseeding can be used in lieu of drilling at double the recommended seeding rates. Where seed is broadcast, firm the seedbed with a cultipacker or roller after seeding. In rocky soils or where site conditions may limit the effectiveness of this equipment, other alternatives may be appropriate (e.g., use of a chain drag) to lightly cover seed after application, as approved by the Environmental Inspector.

VI. OFF-ROAD VEHICLE CONTROL

To each owner or manager of forested lands, offer to install and maintain measures to control unauthorized vehicle access to the right-of-way. These measures may include:

A. signs;

B. fences with locking gates;

C. slash and timber barriers, pipe barriers, or a line of boulders across the right-of-way; and

D. conifers or other appropriate trees or shrubs across the right-of-way.

VII. POST-CONSTRUCTION ACTIVITIES AND REPORTING

A. MONITORING AND MAINTENANCE

1. Conduct follow-up inspections of all disturbed areas, as necessary, to determine the success of revegetation and address landowner concerns. At a minimum, conduct inspections after the first and second growing seasons.

2. Revegetation in non-agricultural areas shall be considered successful if upon visual survey the density and cover of non-nuisance vegetation are similar in density and cover to adjacent undisturbed lands. In agricultural areas, revegetation shall be considered successful when upon visual survey, crop growth and vigor are similar to adjacent undisturbed portions of the same field, unless the easement agreement specifies otherwise.

   Continue revegetation efforts until revegetation is successful.

3. Monitor and correct problems with drainage and irrigation systems resulting from pipeline construction in agricultural areas until restoration is successful.

4. Restoration shall be considered successful if the right-of-way surface condition is similar to adjacent undisturbed lands, construction debris is removed (unless otherwise approved by the landowner or land managing agency per section V.A.6), revegetation is successful, and proper drainage has been restored.

5. Routine vegetation mowing or clearing over the full width of the permanent right-of-way in uplands shall not be done more frequently than every 3 years. However, to facilitate periodic corrosion/leak surveys, a corridor not exceeding 10 feet in width centered on the pipeline may be cleared at a frequency necessary to maintain the 10-foot corridor in an herbaceous state. In no case shall routine vegetation mowing or clearing occur during the migratory bird nesting season between April 15 and August 1 of any year unless specifically approved in writing by the responsible land management agency or the U.S. Fish and Wildlife Service.

6. Efforts to control unauthorized off-road vehicle use, in cooperation with the landowner, shall continue throughout the life of the project. Maintain signs, gates, and permanent access roads as necessary.

B. REPORTING

1. The project sponsor shall maintain records that identify by milepost:

   a. method of application, application rate, and type of fertilizer, pH modifying agent, seed, and mulch used;

   b. acreage treated;

   c. dates of backfilling and seeding;

   d. names of landowners requesting special seeding treatment and a description of the follow-up actions;

   e. the location of any subsurface drainage repairs or improvements made during restoration; and

   f. any problem areas and how they were addressed.

2. The project sponsor shall file with the Secretary quarterly activity reports documenting the results of follow-up inspections required by section VII.A.1; any problem areas, including those identified by the landowner; and corrective actions taken for at least 2 years following construction.

   The requirement to file quarterly activity reports with the Secretary does not apply to projects constructed under the automatic authorization, prior notice, or advanced notice provisions in the FERC's regulations.

South Dakota Game, Fish and Parks

2023

Aquatic Invasive Species

Strategic Management Plan

Kevin Robling
Department Secretary

Tom Kirschenmann
Wildlife Division Director

Jake Davis
Aquatics Program Administrator

John Lott
Aquatics Section Chief

Tanner Davis
AIS Coordinator

Adopted by GFP Commission January 13, 2023

Agency Mission

We serve and connect people and families to the outdoors through effective management of our state's parks, fisheries, and wildlife resources.

Agency Vision

We will conserve our state's outdoor heritage to enhance the quality of life for current and future generations.

Executive Summary

South Dakota Game, Fish and Parks (SDGFP) is a public land administrator and a steward of the state's natural resources. Aquatic Invasive Species (AIS) have the potential to impact numerous aspects of surface waters within the state, several of which pertain to SDGFP, such as recreation. As such, SDGFP has a vested interest in AIS management within the state. This strategic plan is meant to identify the many challenges associated with AIS management and provide a pathway for slowing the spread within the state. Outreach and education are the primary tools available to change the behavior of every surface water user of the state. One of the primary goals of the AIS program is to provide users with the tools they need to implement Best Practices (BPs) every time they use a surface water of the state. As the status and distribution of AIS across the landscape is constantly evolving, this document is also meant to guide activities by SDGFP in response to both new species within the state and changing distributions of species currently established.

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Introduction

Aquatic Invasive Species (AIS) are aquatic plants and animals that have been introduced into waterways in which they do not live naturally. They can affect the natural resources in these ecosystems and the human uses of these resources. Annually, new species are detected in North America and established species have been documented to expand their range. For example, Zebra Mussel (*Dreissena polymorpha*) were first detected in the mid-1980's, but have since spread to numerous states and provinces (USGS data; Figure 1). Despite efforts to stop the spread of species like Zebra Mussel by state, federal and tribal agencies, along with non-governmental organizations, continued expansion has occurred, with new infestations confirmed annually.

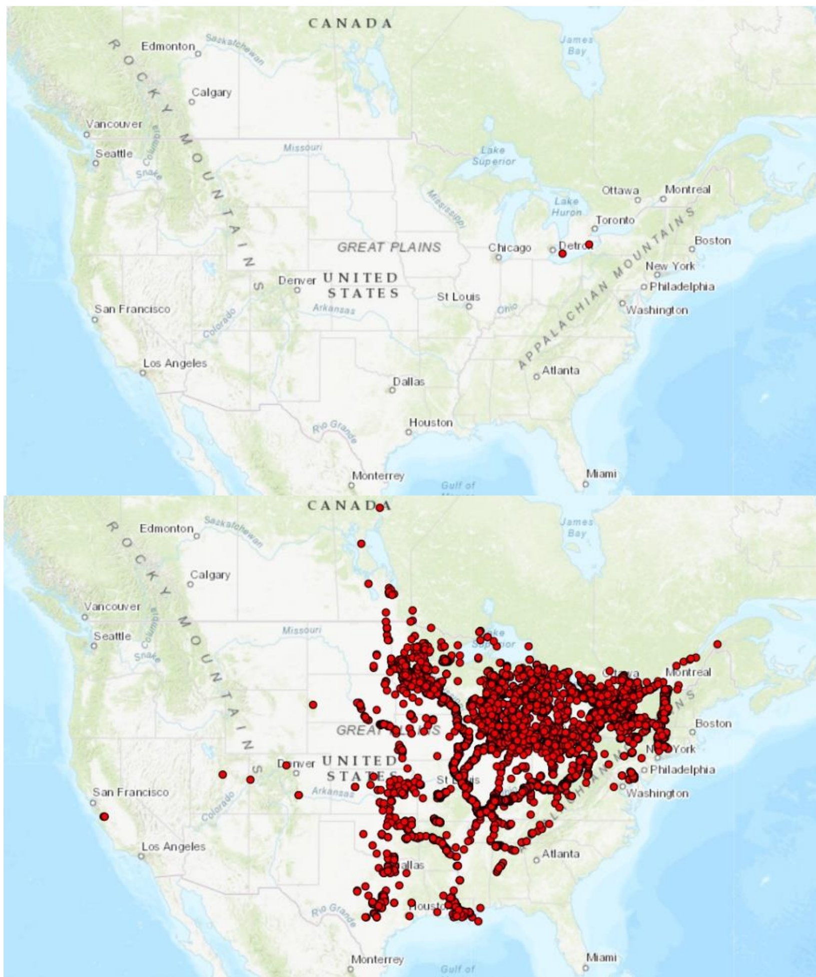

Figure 1. Distribution of Zebra Mussel (*Dreissena polymorpha*) in North American from initial detection in 1986 (top) to known distribution in 2022 (bottom; USGS data).

South Dakota Game, Fish and Parks (SDGFP) works to slow the spread of AIS through outreach and education, regulations, and enforcement. The AIS program within SDGFP has developed over the years as new species have been detected in South Dakota waters and as species have spread within the state. Efforts within the program have and continue to be determined by what is deemed to be most effective and realistic for the State of South Dakota and as such, the primary approach to slowing the spread of AIS focuses on outreach and education. The primary goal is to provide every individual who uses a surface water within the state with the information needed to understand AIS and their impacts, and tools they can put into practice to reduce the risk of spreading any AIS. Additionally, SDGFP has made efforts to evaluate and investigate potential impacts of AIS to the state (Vanderbush et al. 2021), as well as utilizing other published literature (e.g., Lund et al. 2018).

The South Dakota Aquatic Nuisance Species Management Plan (Burgess and Bertrand 2008) was approved by Governor Mike Rounds in 2008. This plan was developed in response to Section 1204 of the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) of 1990 (U.S. Congress 1990), which provides states an opportunity for federal cost share support for implementation of a plan to address AIS. The Department of Game, Fish and Parks led the effort to draft the 2008 state plan in collaboration with multiple state, federal, tribal, and non-governmental organizations, and is responsible for the administration of the plan; however, this plan was broadly designed for use by all entities that may have AIS management responsibilities. In 2016, a SDGFP Strategic AIS Plan was created and implemented. Starting in 2021, AIS Communication Plans have been generated annually as outreach and education has been the primary tool to inform surface water users of infested waters and practices they can adopt to minimize the likelihood of contributing to the spread of AIS.

In addition to this AIS Strategic Plan, Operational and Communication plans will be generated annually by SDGFP. The AIS Operational Plan outlines the details of the SDGFP AIS program in regard to specific actions for a given year. For example, the number and location of Watercraft Inspection and Decontamination sites, as well as methodologies used during inspections and the educational information provided, will be outlined in this document. Additionally, specific Best Practices (BPs) to be utilized by SDGFP staff during production and stocking of fish and actions taken during fieldwork will be included to ensure that these activities do not contribute to the spread of AIS. The annual AIS Communications Plan will outline specific communication strategies and outlets for information. For example, "Communications Toolkits' will be developed and distributed to interested parties, such as Lake Associations, but the information may vary interannually and this will be captured within the Communications Plan. Additionally, partnerships with outside entities, such as marketing agencies, will allow for additional avenues for information dissemination; however, these will also be determined annually.

Annual development of these plans will allow for flexibility between years and ensure that new information and practices are incorporated into the SDGFP AIS program. These plans will be created at the start of the calendar year and shared with the SDGFP Commission and public prior to implementation of the field season (i.e., open water period).

SDGFP Role in AIS Management

SDGFP contributes to AIS management by engaging recreational surface water users to help them slow the spread of AIS to new waters, mitigating impacts to recreation where possible, and coordinating with other entities on AIS management activities. In cases where SDGFP may not or does not have authority for surface water use(s), collaboration and cooperation with the necessary entities occurs.

To fully implement the SDGFP AIS Strategic Plan, coordination with other South Dakota state agencies is required. Depending on certain roles, responsibilities and authorities, partnering agencies play a large role in slowing the spread of AIS in South Dakota (Table 1).

Table 1. List of South Dakota state agency partners and examples roles for Aquatic Invasive Species program assistance.

South Dakota state agency	Example role(s)
Department of Transportation	• Installation of signage (Rapid Response plan). • Interstate signage during peak boating weekends • Locations for watercraft inspection/decontamination stations
Department of Public Safety	• Coordination of road-side watercraft inspection and decontamination locations
Department of Agriculture and Natural Resources	• Engagement of non-recreational surface water users.
Department of Revenue	• Distribution of information rack cards to County Treasurers for inclusion in watercraft registrations.
Department of Tourism	• Dissemination of educational materials • Partnering in marketing campaigns

Inventory

Aquatic Resources of South Dakota

South Dakota lies almost entirely within the Missouri River Basin, although a small portion in the northeast corner of the state flows into the Red River. Lakes and impoundments of various sizes can be found throughout the landscape. Major rivers in South Dakota include the Grand, Moreau, Cheyenne, Bad, White, James, Vermillion, and Big Sioux (Figure 2). The largest waters, by area, in South Dakota are the Missouri River and its associated reservoirs Oahe, Sharpe, Francis Case, and Lewis and Clark.

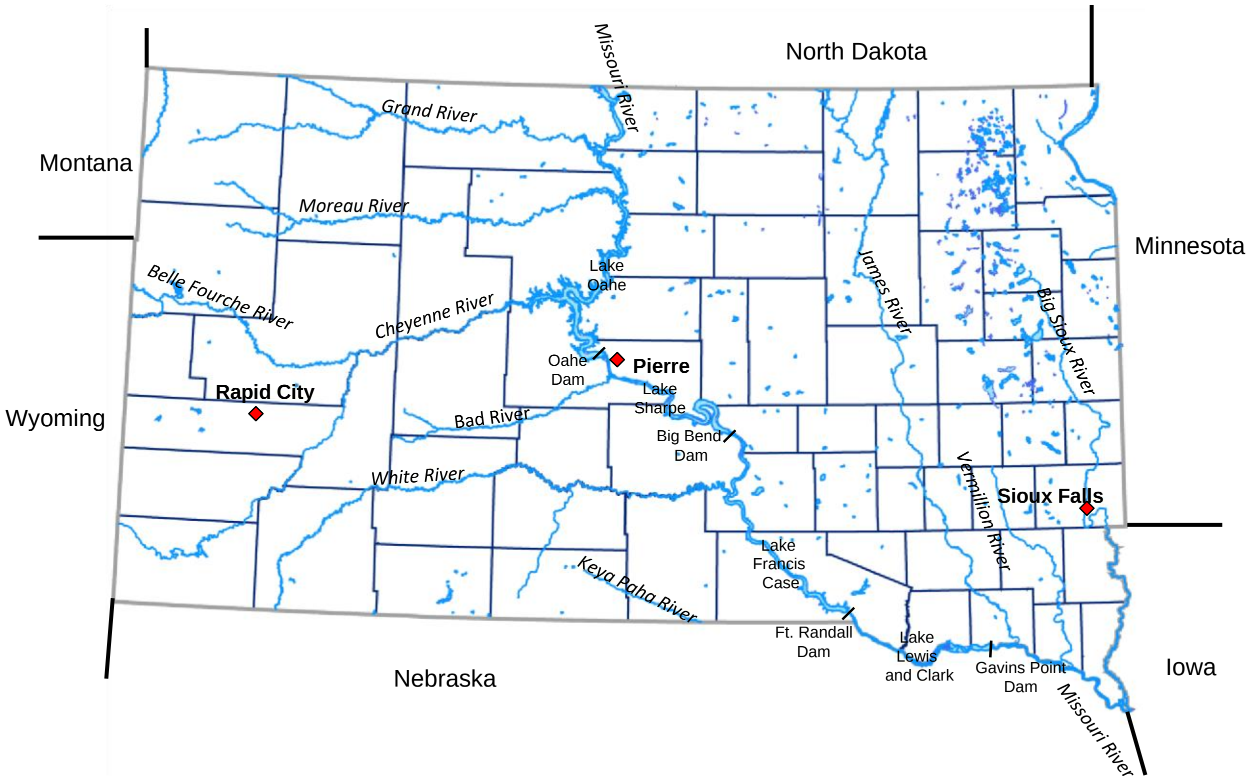

Figure 2. Aquatic resources of South Dakota.

The aquatic resources of South Dakota include a variety of standing and flowing water systems that vary significantly in size, biodiversity, and economic and recreational value. While it may vary depending on precipitation cycles, nearly 10,000 waterbodies over 10 acres are present within the state. Additionally, nearly 500 boat ramps exist across the state that provide access to these numerous waterbodies. In several parts of the state, the connectivity within these systems of waterbodies is high and multiple waterbodies can be connected through flowing waters.

Aquatic Invasive Species Present in South Dakota

Like many other states and provinces, various AIS fish, plant, and invertebrate species have become established in the state (Table 2). The list of species classified as AIS in South Dakota, along with current AIS regulations at the time of plan adoption, can be found in Appendix A. Following detection, the geographic range of these species within South Dakota largely remained localized to single waterbodies; however, many species distributions within the state have increased in subsequent years.

Table 2. Aquatic Invasive Species known to be present in South Dakota, by species and waterbody, as of the date of plan adoption.

		Fish*				Plants*						Invertebrates					
		Bighead Carp	Silver Carp	Grass Carp	European Rudd	Brittle Naiad	Curly Pondweed	Didymo	Eurasian Water-milfoil	Purple Loosestrife	Flowering Rush	New Zealand Mudsnail	Red Swamp Crayfish	Rusty Crayfish	Zebra Mussel	Asian Clam	Red Rimmed Melania
Waterbody	Missouri River																
	*Lake Oahe				x		x		x								
	*Lake Sharpe				x		x		x	x					x		
	*Lake Francis Case				x		x		x	x					x		
	*Lewis & Clark Lake				x	x	x		x	x				x	x	x	
	*Below GPD	x	x	x	x								x	x	x	x	
	James River	x	x	x													
	Big Sioux River																
	*Below Falls Park	x	x	x													
	Vermillion River				x												
	*Below E. Vermillion SRA	x	x	x													
	Fall River																
	*Inside Hot Springs																x
	Cascade Creek																
	*Cascade Springs																x
	Beaver Creek (Custer)											x					
	Angostura Reservoir						x									x	
	Big Stone Lake						x										
	Canyon Lake						x										
	Castle Creek							x									
	Clear Lake (Marshall)														x		
	Dahme Quarry														x		
	Blue Dog Lake														x		
	Enemy Swim Lake														x		
	Herrick Lake						x										
	Interstate Lakes (Brookings)				x												
	Lake Alice				x		x										
	Lake Byron	x	x														
	Lake Cochrane														x		
	Lake Faulkton										x						
	Lake Louise										x						
	Lake Kampeska														x		
	Lake Madison				x												
	Lake Mitchell (Davison)						x								x		
	Lake Roosevelt						x										
	Lake Traverse						x										
	Lake Vermillion				x												
	Lake Yankton						x								x		
	McCook Lake					x	x								x		
	Mina Lake				x												
	Nelson Slough						x										
	Newell Reservoir				x												
	Pactola Reservoir				x										x		
	Pickerel Lake						x								x		
	Rapid Creek						x	x		x							
	Rohn Lake						x										
	Roy Lake						x										
	Sheridan Lake				x		x										
	South Rush Lake														x		
	Stockade Lake						x										
	Multiple private ponds			x													
	Bait Dealer Pond													x			
		*Common Carp and Phragmites are widely distributed and can be found statewide															

Management Components

Aquatic Invasive Species management is comprised of four key components: prevention, containment, mitigation and eradication.

1. Prevention

While prevention is an important part of AIS management, it is also challenging because of the evolving movement of AIS across the landscape, both within and outside South Dakota. New AIS are regularly introduced to the United States, and the number and complexity of vectors that have the potential to transport AIS to South Dakota presents a significant challenge. Many aquatic resources in South Dakota have multiple users (recreation, construction, industry, agriculture, municipal water, etc.), which results in many diverse user groups and many vectors for transport.

Reducing the likelihood of AIS introductions to new waters by surface water users is largely attempted through outreach and education activities due to the high volume of waters and access points to them. It is the responsibility of every surface water user of the state to make efforts to reduce the likelihood that they are introducing AIS every time they use aquatic resources of the state. As such, providing users with the information needed to implement BPs every time they use a surface water of the state is essential.

Adequate regulations are an important tool in slowing AIS from entering the state and keeping established populations from spreading to new water bodies or new areas of a water body. Compliance by users of these regulations helps ensure that BPs are being utilized. Enforcement of AIS regulations aids in compliance, as well as outreach and education. It is important to ensure the balance between reasonable use of regulations and ecological protection is maintained.

2. Containment

With nearly 10,000 waterbodies and roughly 500 boat ramps statewide, the geographic size and complexity of South Dakota's aquatic resources makes containment efforts challenging. Outreach and education are primary tools for containment efforts. Notifying users of current AIS distributions and vectors of transport are key components to reducing the likelihood of increased spread. Additional control activities include sampling and monitoring water bodies for AIS populations and attempting to eradicate populations where and when feasible.

3. Mitigation

Mitigation in AIS management includes efforts to prevent impacts of AIS, by preventing introductions, or reducing impacts of AIS on the environment or surface water users. Specific impacts and severity vary with species and the environment where they are introduced. In some cases, impacts may be minimal to nonexistent. On the other hand, impacts may be much larger and more complex. In addition to specific actions and costs associated with mitigation efforts, identifying and coordinating of specific mitigation needs (hydropower, watercraft, irrigation) and disseminating information to user groups, can be challenging.

Outreach and education are important tools of mitigation. This can include educating users on ways to reduce both the risk of spreading AIS while using surface waters of the state or dealing with already established AIS. Research focusing on mitigating AIS impacts is also an important focus, both within and outside South Dakota.

4. Eradication

Eradication of established AIS is often the most difficult aspect of management. Few options exist once a population becomes established and many of these practices are ineffective. Examples of eradication efforts exist and SDGFP, along with aspects specific to South Dakota, consider these when weighing options. In general, attempts to eradicate AIS are extremely costly, largely ineffective, and are likely infeasible in most instances.

Goal, Objectives and Strategies

Goal: Slow the spread of AIS to and within South Dakota.

Objective 1: Educate all surface water users about the importance of CLEAN, DRAIN, DRY in slowing the spread of AIS.

Strategy 1.1: Develop and implement annual SDGFP AIS Communications Plans.

Strategy 1.2: Utilize internal communications staff to disseminate AIS education and outreach material using all available media platforms.

Strategy 1.3: Contract with outside entities for education and outreach efforts that cannot be handled internally.

Strategy 1.4: Provide AIS education and outreach material to external partners (e.g., lake associations, lake service providers, wholesale and retail bait dealers, tourism boards, and other government agencies, etc.) to increase viewership.

Strategy 1.5: Utilize localized education and outreach efforts (e.g., signage, watercraft inspections) to inform users of specific AIS infestations within the state.

Objective 2: Utilize regulations and enforcement as tools to slow the spread of AIS by requiring users to implement specific behaviors for cleaning, draining, and drying watercraft and related equipment.

Strategy 2.1: Annually review AIS regulations to determine their effectiveness at slowing the spread of AIS and recommend necessary changes.

Strategy 2.2: Utilize internal communication staff and external partners to educate users on current AIS regulations.

Strategy 2.3: Utilize internal and engage external law enforcement to enforce AIS regulations.

Strategy 2.4: Use watercraft inspection stations as the primary tool to actively engage watercraft users on complying with regulations and for coordination with law enforcement staff on enforcement activities.

Strategy 2.5: Utilize AIS Workforce Recruitment Plan (Appendix B) to fill advertised AIS positions.

Objective 3: Detect and monitor existing AIS populations.

Strategy 3.1: Utilize SDGFP staff to detect new AIS infestations while conducting fieldwork and monitor existing populations.

Strategy 3.2: Provide avenues for the general public to participate in AIS monitoring (e.g. Citizen Monitoring through SDLEASTWANTED.SD.GOV).

Strategy 3.3: Utilize SDGFP communications staff to notify the public of new infestations and inform them of current AIS distributions in the state.

Strategy 3.4: Execute the Rapid Response Plan (Appendix C) for any new Zebra or Quagga mussel infestation.

Objective 4: Support research on AIS in South Dakota.

Strategy 4.1: Partner with other entities to support research that identifies, predicts, and reduces the likelihood of AIS introductions or provides recommendations on ways to mitigate impacts of AIS present in the state.

Strategy 4.2: SDGFP and partners will support research on potential management alternatives for their effectiveness at reducing impacts of AIS on native species and human users**.**

Objective 5: Minimize risk of spread of AIS during GFP activities.

Strategy 5.1: Keep staff up to date on current AIS and distributions within the state.

Strategy 5.2: Utilize internally developed Aquatic Invasive Species-Hazard Analysis Critical Control Point (HACCP) plans and published practices (e.g. Schall 2019) to reduce risk of spread during fish management and hatchery production activities.

Strategy 5.3: Utilize any new information to update internal BPs in regard to mitigating the spread of AIS during activities.

Objective 6: Coordinate AIS management efforts with parties interested in surface water use of South Dakota.

Strategy 6.1: Annually engage other state agencies and reference opportunities to partner with GFP on AIS management into GFP's annual communication and field operations work plans.

Strategy 6.2: Engage interested parties on AIS communication and field operations efforts and provide them with information on how to mitigate impacts experienced.

Strategy 6.3: Share annual updates on AIS with other state agencies and surface water uses within the state and use input received in development of annual communications and field operations plans.

Strategy 6.4: Provide Lake Associations with options to partner with GFP on AIS efforts (e.g., outreach, inspections, etc.) at specific waterbodies.

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Appendix A: Aquatic Invasive Species Regulations as of January 1, 2023

South Dakota Codified Laws

41-13A-1. Definitions.
Terms used in this chapter mean:
(1) "Aquatic invasive species," an aquatic species that is not native to the state, including the seeds, eggs, spores, or larvae of the species, or other biological material capable of propagation, and whose presence within the state may cause economic or environmental harm;
(2) "Conveyance," a motorized or nonmotorized boat and associated equipment that may come in contact with water or that is able to transport water. A conveyance includes any trailer, engine, motor, live well, ballast tank, bilge area, anchor, and any other item that may come in contact with water or is able to transport water that could harbor an aquatic invasive species;
(3) "Decontamination," a process used to kill, destroy, or remove aquatic invasive species and other organic material that may be present in or on a conveyance;
(4) "Inspection," a visual and tactile examination of a conveyance to determine whether it may harbor any organisms or other organic material that could present a risk of spreading an aquatic invasive species;
(5) "Waters," all waters within the jurisdiction of the state used for recreational boating, including rivers, streams, and natural or manmade lakes, ponds, and reservoirs.

41-13A-2. Aquatic invasive species—Prohibitions—Violation as misdemeanor.
No person may possess, import, ship, or transport within this state any aquatic invasive species unless authorized by the commission in rules promulgated under § 41-2-18.
A violation of this section is a Class 2 misdemeanor. A second or subsequent violation of this section within one year is a Class 1 misdemeanor.

41-13A-3. Conveyance placement—Requirements—Violation as misdemeanor.
No person may place a conveyance, or cause a conveyance to be placed, into waters within this state without first meeting the requirements in § 41-13A-4 unless authorized by the commission in rules promulgated under § 41-2-18.
A violation of this section is a Class 2 misdemeanor. A second or subsequent violation of this section within one year is a Class 1 misdemeanor.

41-13A-4. Conveyance removal—Requirements—Violation as misdemeanor.
Any person removing a conveyance from waters shall, to the extent possible, do the following:
(1) Clean the conveyance by removing all visible organic material, including plants, animals, and mud;
(2) Drain the conveyance by removing any plug or other barrier that prevents water drainage and running any pumps on board to expunge water; and
(3) Comply with any other requirements and protocols for the cleaning, draining, and drying of a conveyance established by the commission in rules promulgated under § 41-2-18.

41-13A-5. Inspection stations—Required inspections—Violation as misdemeanor.
To prevent the introduction, importation, infestation, and spread of aquatic invasive species, the department may establish aquatic invasive species inspection stations at any location within the state including interstate borders, highways or other roads, locations adjacent to or near public waters, and at department offices. Any person with a conveyance is required to stop at an inspection station. The department shall receive approval from the Department of Transportation before establishing an inspection station along any road that is part of the state trunk system. Failure to comply with the provisions of this section is a Class 2 misdemeanor. A second or subsequent violation of this section within one year is a Class 1 misdemeanor.

41-13A-6. Inspection stations—Inspections—Decontamination.
At inspection stations established under § 41-13A-5, authorized department personnel may inspect the exterior of any conveyance for the presence of organisms or organic material that may harbor aquatic invasive species. Authorized personnel may examine any interior portion of a conveyance that may carry or transport water or organic material, including an engine, motor, live well, ballast tank, or bilge area. A law enforcement officer may stop a person with a conveyance at a location other than an inspection station if the person fails to stop at an inspection station or fails to comply with required inspection and decontamination procedures. During the inspection, personnel may also check for compliance with the requirements established in §§ 41-13A-2 to 41-13A-4, inclusive.

If any organisms or organic material that may harbor aquatic invasive species are found or suspected to be present as a result of the inspection, the department may decontaminate the conveyance or order the decontamination of the conveyance.

41-13A-7. Law enforcement authority—Inspections—Decontamination.
A law enforcement officer may only stop a conveyance at a location other than an inspection station established under this chapter, and may only inspect the conveyance for the presence of organisms, or organic material that may harbor aquatic invasive species if the conveyance is visibly transporting organisms or organic material, including animals, plants, or mud, or the law enforcement officer otherwise reasonably believes, based on articulable facts, that the conveyance is in violation of any of the provisions of §§ 41-13A-2 through 41-13A-4. If a law enforcement officer conducts an inspection of a conveyance and finds the presence of organisms, organic material, or water, that may harbor aquatic invasive species, a law enforcement officer may do the following:

(1) Escort the conveyance to the nearest inspection station for immediate decontamination;
(2) Issue an order requiring the decontamination of the conveyance; or
(3) Detain the conveyance until the decontamination is complete.

South Dakota Administrative Rules

41:10:04:01. List of aquatic invasive species. Species classified as aquatic invasive species in the state are as follows;

(1) Fish:

(a) Black carp, **Mylopharyngodon piceus**;
(b) Common carp, **Cyprinus carpio**;
(c) Grass carp, **Ctenopharyngodon idella**;
(d) Bighead carp, **Hypophthalmichthys nobilis**;
(e) Silver carp, **Hypophthalmichthys molitrix**;
(f) European rudd, **Scardinius erythrophthalmus**;
(g) Giant snakehead, **Channa micropeltes**;
(h) Northern snakehead, **Channa argus**;
(i) Bullseye snakehead, **Channa marulius**;
(j) Blotched snakehead, **Channa maculata**;
(k) Western mosquitofish, **Gambusia affinis**;
(l) Round goby, **Neogobius melanostomus**; and
(m) White perch, **Morone americana**;

(2) Plants:

(a) Brittle naiad, **Najas minor**;
(b) Curly pondweed, **Potamogeton crispus**;
(c) Didymo, **Didymosphenia geminata**;
(d) Eurasian water-milfoil, **Myriophyllum spicatum**;
(e) Purple loosestrife, **Lythrum salicaria**;
(f) Flowering rush, **Butomus umbellatus**;
(g) Common reed, **Phragmites australis;** and
(h) Starry stonewort, **Nitellopsis obtusa**;

(3) Invertebrates:

(a) New Zealand mudsnail, **Potamopyrgus antipodarum**;
(b) Rusty crayfish, **Orconectes rusticus**;
(c) Zebra mussel, **Dreissena polymorpha**;
(d) Quagga mussel, **Dreissena rostriformis bugensis**;
(e) Asian clam, **Corbicula fluminea**;
(f) Red rimmed melania, **Melanoides tuberculata**;
(g) Red swap crayfish, **Procambarus clarkii**; and
(h) Spiny waterflea, **Bythotrephes longimanus**.

41:10:04:02. Aquatic invasive species exemptions. The following are exempt from SDCL 41-13A-2:
(1) A person possessing a scientific collectors permit issued by the department;
(2) A person authorized by the department to stock triploid grass carp for pond management purposes;

(3) A person contracted by the department to conduct commercial fishing operations as authorized in SDCL 41-13-7;
(4) A person in the process of removing an aquatic invasive species from a conveyance;
(5) An owner or agent of the owner of a conveyance in the process of transporting the conveyance for decontamination using a department approved procedure;
(6) An employee of a business approved by the department to transport and possess conveyances for the purpose of decontamination;
(7) A commercial plant harvester operating within the requirements of a department approved work plan or a lakeshore property owner operating within the requirements of a department approved permit; and
(8) A lakeshore property owner in the process of transporting aquatic invasive species, for disposal, in a manner that minimizes possible introduction to new waters.
In the case of fish and crayfish species, only dead specimens may be transported or possessed.

41:10:04:02.01. Aquatic species conveyance launching and removal exceptions. The following are exempt from SDCL 41-13A-3 and 41-13A-4:
(1) An owner and agent of the owner of a conveyance with dressinid mussels attached that is subsequently launched directly into the infested water from which it was removed, if the conveyance was stored on the riparian property of the owner or at a marina business property on the infested water, prior to launch; and
(2) An owner and agent of the owner of a conveyance with a shooting or observational blind constructed of aquatic macrophytes cut above the water line, attached to or in the conveyance.

41:10:04:03. Boat restrictions. Except for emergency response boats or as authorized by the secretary, all trailered boats must have all drain plugs, bailers, valves, and other devices used to control the drainage of water opened or removed, except while in a boat ramp parking area or while being launched or loaded.

41:10:04:05. Fish and bait transportation restrictions. Except as authorized by the Secretary, a person may not transport fish or aquatic bait in water obtained from a lake, river, or stream except when in a boat ramp parking area.

41:10:04:06. Infested water -- Definition. For purposes of this chapter, "infested water" means a body of water that has an established zebra or quagga mussel population, a water body downstream of an infested water with a likelihood of becoming infested, or waters that are located outside this state and designated by a legal jurisdiction as infested by zebra or quagga mussels.

41:10:04:10. Decontamination procedure. The department approved decontamination procedures are protocols described in "Uniform Minimum Protocols and Standards for Watercraft Inspection and Decontamination Programs for Dreissenid Mussels in the Western United States" (UMPS), 3rd edition, published by the Pacific States Marine Fisheries Commission.

Appendix B: Aquatic Invasive Species Workforce Recruitment Plan

Goal: Recruit qualified applicants for all positions posted for the AIS program to help slow the spread of AIS within South Dakota.

The South Dakota Game, Fish and Parks (SDGFP) Aquatic Invasive Species (AIS) program is staffed using a combination of full-time, temporary and contract employees. As such, multiple approaches and timelines are associated with the hiring process to fill positions each year.

For SDGFP internships, the timeline will follow what is established by the South Dakota Bureau of Human Resources (SDBHR) in association with the Executive Internship Program (EIP). Specific dates may vary interannually and the pay level will be determined by the South Dakota Bureau of Human Resources (SDBHR) based on the duties listed on the requisition request. Applicants must be full-time students at a college or university and have sophomore standing or above by the end of the fall semester or must currently be enrolled at a vocational-technical school and have completed one year (nine months) by the start of the internship.

For SDGFP seasonal positions, the SDBHR timelines and requirements for applications are more flexible. Additionally, the education enrollment status requirement does not apply. Applicants need to be 18 years of age.

Employees hired by organizations under contract with SDGFP (e.g., County Conservation Districts) are hired through methods specific to a given entity.

This document is meant to provide a pathway for both positions to be posted and disseminated in efforts to reach as many qualified candidates as possible. As a common goal exists to hire all advertised positions, SDGFP will assist any partner organization with development of positions descriptions and postings.

Checklist:

Date completed	Action
	Create position description
	Post position (e.g., BHR website/partner location)
	Send to list of institutions (Table 1)
	Post on GFP social media
	Attend job fairs at educational institutions
	Send GFP emails with job announcements
	Send announcements to NGO partners (e.g., lake associations)

Table 1. List of institutions to send position posting information.

Institution	**Location**
South Dakota State University	Brookings, SD

University of South Dakota	Vermillion, SD
South Dakota School of Mines and Technology	Rapid City, SD
Black Hills State University	Spearfish, SD
Northern State University	Aberdeen, SD
Dakota State University	Madison, SD
Lake Area Technical College	Watertown, SD
Western Dakota Technical College	Rapid City, SD
Southeast Technical College	Sioux Falls, SD
Mitchell Technical College	Mitchell, SD
Dakota Wesleyan University	Mitchell, SD
Augustana University	Sioux Falls, SD
University of Sioux Falls	Sioux Falls, SD
Chadron State University	Chadron, NE
Southwest Minnesota State University	Marshall, MN
Mount Marty University	Yankton, SD
Presentation College	Aberdeen, SD
Oglala Lakota College	Kyle, SD
Sisseton Wahpeton College	Sisseton, SD
Sinte Gleska University	Mission, SD

Appendix C: South Dakota Zebra and Quagga Mussel Rapid Response Plan

Upon confirmation of a new water being infested with Zebra or Quagga Mussel, the below response plan will be implemented.

Immediately upon confirmation of a new infestation, South Dakota Game, Fish and Parks (GFP) Rapid Response Team members will notify the GFP Cabinet Secretary and Wildlife Division Director, the South Dakota Governor's Office, GFP Commissioners, other GFP staff, and other affected governmental agencies of the infestation.

Rapid Response Team members may include:

- **Game, Fish and Parks** – the AIS Coordinator, Fisheries Management Program Administrator, Aquatic Section Chief, Area Fisheries Supervisor, Regional Conservation Officer Supervisor, and the Communications Director
- **Other Governmental Entities** – other – state, federal, tribal, and municipal agency representatives who may have regulatory authority or the ability to contribute to response efforts.

The AIS Coordinator and Program Administrator will assemble the response team for a specific water.

<u>Immediate Response</u>

1. The GFP Communications Director will coordinate dissemination of information on the new infestation to include:

- Press releases regarding the new infestation will be developed in collaboration with other management authorities and shared with media contacts within 24 hours of confirmation of the infestation.
- Targeted emails being shared with anglers/boaters and/or park users.
- Social media post regarding new infestation on GFP social media platforms.
- Addition of the infested waterbody to AIS map and Public Fishing Access map.
- Addition of the infested waterbody to SDLeastWanted.sd.gov.
- Addition of the infested waterbody to geofencing efforts of the AIS marketing campaign.

2. GFP Aquatics Section Staff will organize a meeting of the Rapid Response Team to determine immediate actions to take in response to the infestation, with additional meetings scheduled, as needed.

- Immediate actions will include:

- Coordinate with other entities with management authority for the infested water and distribute a joint press release within 1 day of confirmation of the infestation.
- Place high-profile signs, 18" x 24", on GFP access areas where no other approval is required within 2 days. Placement on water bodies outside GFP authority may take longer until approval is received from the managing agency or entity.
- Position the large (4' x 8') notification signs at high profile locations at the water body entrances within 5 days. DOT assists with permanent placement of these signs using their equipment and trucks; however, temporary placement will occur if permanent cannot be accomplished within the timeline (e.g., frozen ground).
- Determining the best locations for actively engaging boaters using the infested water and sharing information on decontamination requirements and how to Clean, Drain, and Dry equipment.
- Identifying groups of people and entities that will be potentially affected by the infestation, including marina operators and slip holders, water service providers (weed harvesters, boat dock and lift businesses), lake association members, municipalities, irrigators, and sportsman and conservation groups.
- Sharing information on decontamination requirements and mitigation techniques with all publics.

Continued Response

3. After the conclusion of the initial boating season of infestation, Rapid Response Team members will meet to develop an action plan for slowing the spread of zebra mussels to other waters.

•Actions will include:

- Working with marinas, slip holders, and lakeshore property owners to reduce colonization of mussels on watercraft and related equipment.
- Identifying parties interested in providing decontaminations for watercraft, and boat docks and lifts, instructing them in proper decontamination procedures, and sharing the availability of services with affected parties.
- Working with other managing government entities on future coordinated AIS efforts.