Managing Environmental Aspects Associated with Exploration and Production Operations Including Hydraulic Fracturing

ANSI/API RECOMMENDED PRACTICE 100-2
FIRST EDITION, AUGUST 2015

AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API is not undertaking to meet the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations to comply with authorities having jurisdiction. Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the safety data sheet.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Users of this Recommended Practice should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

Information concerning safety and health risks and proper precautions with respect to particular materials and conditions should be obtained from the employer, the manufacturer or supplier of that material, or the material safety data sheet.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, NW, Washington, DC 20005.

Copyright © 2015 American Petroleum Institute

Foreword

The verbal forms used to express the provisions in this specification are as follows:

— the term “shall” denotes a minimum requirement in order to conform to the specification;

— the term “must” denotes a requirement in order to conform with regulatory obligations;

— the term “should” denotes a recommendation or that which is advised but not required in order to conform to the specification;

— the term “may” is used to express permission or a provision that is optional;

— the term “can” is used to express possibility or capability.

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

Contents

Contents

Page

Managing Environmental Aspects Associated with Exploration and Production Operations Including Hydraulic Fracturing

1 Scope

1.1 General

This document provides recommended practices applicable to the planning and operation of wells, and hydraulically fractured wells. Topics covered include recommendations for managing environmental aspects during planning; site selection; logistics; mobilization, rig-up, and demobilization; and stimulation operations. Also, this document includes guidance for managing environmental aspects during well construction. This document provides recommendations for the following topics:

a) baseline groundwater sampling;

b) source water management;

c) material selection;

d) transportation of materials and equipment;

e) storage and management of fluids and chemicals;

f) management of solid and liquid wastes;

g) air emissions;

h) site planning;

i) training;

j) noise and visual resources.

This document provides a general discussion of exploration and production operations, which does not supersede the review of applicable local, state, and federal regulatory requirements. Operators should consider available industry standards and guidance that can provide additional information.

In addition to this document, API 100-1 contains recommended practices for well construction and fracture stimulation design and execution as it relates to well integrity, groundwater protection and fracture containment for onshore wells. The recommended practices relate to two areas: well integrity during the design and installation of well equipment, and fracture containment during the design and execution of hydraulic fracturing treatments.

1.2 Conditions of Applicability

This document provides technical guidance only, and practices included herein may not be applicable in all regions and/or circumstances. This document does not constitute legal advice regarding compliance with legal or regulatory contractual requirements, risk mitigation, or internal company policies and procedures, where applicable. Where legal or regulatory requirements are mentioned, this document is not intended to be all-inclusive. The operator is responsible for determining compliance with applicable legal or regulatory requirements.

2 Normative References

The following referenced document is indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API Recommended Practice 68, *Recommended Practice for Oil and Gas Well Servicing and Workover Operations Involving Hydrogen Sulfide*

3 Terms, Definitions, Acronyms, and Abbreviations

3.1 Terms and Definitions

For the purposes of this document, the following terms and definitions shall apply.

3.1.1
additive
A liquid or solid chemical product used in the blending of fluid, such as those used in fracturing, drilling, and cementing.

3.1.2
anisotropy
A condition of unequal geomechanical properties along different axes or directions.

NOTE Can include differential axes of stress.

3.1.3
aquifer
A subsurface formation that is sufficiently permeable to conduct groundwater and to yield economically significant quantities of water to wells and springs.

3.1.4
base fluid
The primary liquid or gas component or diluent used in blended-solutions, such as those used in hydraulic fracturing.

3.1.5
catchments
A structure, such as a basin or reservoir, used for collecting or draining fluid.

3.1.6
chain of custody
Documentation of the movement, handling, and transfer of samples or data starting from the point of capture.

3.1.7
completion
The activities and methods to prepare a well for production, including casing perforation, formation preparation, and the installation of equipment to produce a well following drilling.

3.1.8
constituent
Individual chemical or component.

3.1.9
development
The phase of the field life-cycle after exploration when an oil or gas field is determined to be economically viable.

NOTE This phase involves the construction of one or more wells and related facilities and infrastructure for the purposes of production.

3.1.10
environmental aspects
Elements of exploration and production activities or materials or services that can interact with the environment.

3.1.11
exploration
The phase of the field life-cycle involving the search for rock formations associated with oil or natural gas deposits, and can involve geophysical prospecting and/or exploratory drilling.

3.1.12
flowlines
The pipe between the wellhead and the production facilities through which produced fluids flow.

3.1.13
flowback <verb>
The act of recovering produced fluids from the formation after hydraulic fracturing operations.

3.1.14
fresh water
Water generally characterized by having low concentrations of dissolved solids.

NOTE Multiple regulatory and legal definitions of this term exist and should be checked for applicability to a specific situation.

3.1.15
gathering lines
Pipelines used to transport oil or gas after primary separation to a processing or compression facility or to the point of custody transfer or sale.

3.1.16
high-pressure piping
treating iron
The temporary surface piping, valves and manifolds necessary to deliver a fluid treatment to the wellbore from the mixing and pumping equipment.

3.1.17
hydraulic fracturing
A completion operation in which a hydraulic fracturing fluid is pumped down a well into a target formation under pressure high enough to exceed the formation fracture gradient to create fractures through which oil or gas can flow into the well bore.

3.1.18
hydraulic fracturing fluid
A fluid blend that can include a base fluid, proppant, and other additives, that is expressly designed to hydraulically induce fractures in the target formation.

3.1.19
impoundment
An earthen-bermed or excavated storage area, above- or below-grade, to store fluid used in onshore operations.

3.1.20
isotopic analyses
An analysis of a sample for stable isotopes, usually carbon or hydrogen.

3.1.21
liquid waste
solid waste
Any solid, semi-solid, liquid or contained gaseous material that is intended for disposal.

3.1.22
mitigation
An action taken to offset, reduce, or compensate for an impact.

3.1.23
non-potable groundwater
Subsurface water not suitable for consumption by humans or animals without treatment.

3.1.24
pad
well pad
The ground surface where wells and production equipment are placed and/or operations conducted.

NOTE 1 A pad is usually constructed to provide a stable surface for equipment used in exploration and production (E&P) activities.

NOTE 2 Several wells can be located on one pad to reduce the overall surface disturbance.

3.1.25
potable groundwater
Subsurface water suitable for consumption by humans or animals with or without treatment.

3.1.26
primacy
A legal authority granted to a state by the federal government that allows state agencies to implement federal regulatory programs with federal oversight.

3.1.27
primary containment
The tanks, pipes, vessels, or containers that first come in contact with the material.

3.1.28
produced water
Any type of water produced from oil and gas wells.

3.1.29
produced fluid
Fluids recovered from a well that can contain a combination of produced water, oil, gas, and additives.

3.1.30
production
The phase of the field life-cycle that occurs after successful exploration and development and during which hydrocarbons are economically recovered from an oil or gas field.

3.1.31
project area
The area of exploration or development that includes one or more well pads and well sites.

3.1.32
proppant
Natural, treated, or man-made particles pumped into a formation during a hydraulic fracturing operation to keep fractures open.

3.1.33
receptor
People, organisms, environs, or facilities that are susceptible to the potential effects of exposure.

3.1.34
reuse
The act of using fluid or material again, with or without processing.

3.1.35
secondary containment
Material, equipment, facilities used to limit the spread or discharge of fluids that are inadvertently released from primary containment.

3.1.36
slickwater
A type of water-based hydraulic fracturing fluid that uses friction reducing additives for the purpose of reducing injection pump pressures.

3.1.37
sodium adsorption ratio
SAR
Ratio of the concentration of sodium ions $[Na^+]$ to the concentration of calcium $[Ca^{2+}]$ and magnesium $[Mg^{2+}]$ ions, expressed in meq/L, as calculated in the following equation.

$$\mathrm{SAR} = \frac{[\mathrm{NA}^+]}{\sqrt{\frac{1}{2}([\mathrm{Ca}^{2+}] + [\mathrm{Mg}^{2+}])}}$$

3.1.38
stakeholders
A person, entity, or organization that is materially affected by the outcome of an operational activity at a site or a regulatory, policy or management decision.

3.1.39
surface water
A body of water naturally open to the atmosphere.

3.1.40
total dissolved solids
TDS
The dry weight of dissolved material, organic and inorganic, contained in water and usually expressed in parts per million.

3.1.41
total petroleum hydrocarbons
A concentration or mass of petroleum hydrocarbon constituents in a given amount of media.

3.1.42
waste water
Water that has been used in an application and contains constituents no longer useful.

3.1.43
water rights
Legal access and authority to use a water source designated to a user.

3.1.44
well site
The area surrounding and contiguous to a single or multiple-well pad.

3.2 Acronyms and Abbreviations

BMP	best management practice
BTEX	benzene, toluene, ethylbenzene, xylenes
CFR	*Code of Federal Regulations*
DOT	Department of Transportation
E&P	exploration and production
EPA	Environmental Protection Agency
LPG	liquid petroleum gas
PPE	personal protection equipment
QA/QC	quality assurance/quality control
MS/MSD	matrix spike/matrix spike duplicate
SAR	sodium absorption ratio
SDWA	Safe Drinking Water Act
SMP	stormwater management plan
SDS	safety data sheet [formerly known as a material safety data sheet (MSDS)]
SOP	standard operating procedure
SPCC	spill prevention, control, and countermeasures
TDS	total dissolved solids
UIC	underground injection control
VOC	volatile organic compound

4 Planning

4.1 Planning and Design Considerations

Planning and design for exploration, development, and production operations is essential to managing the environmental aspects effectively and should be started at the conceptual stages of site development. Planning allows the operator to better anticipate issues and events prior to execution of the drilling and completions including hydraulic fracturing operations. Planning also allows for consideration of external factors that may not be obvious to the operator when conceptualizing the project. During the planning process, a single point of contact should be established who has overall responsibility for the project and can direct individual leads for the various activities.

Before site construction begins, logistics and timing for the following should be taken under careful consideration:

a) site selection (see Section 5);

b) local, state, and federal legal and regulatory requirements including relevant permitting for the project;

c) community outreach and engagement (see API 100-3);

d) spill prevention, control, and response (see Section 6);

e) logistics (see Section 7);

f) baseline ground water sampling (see Section 8);

g) source water management (see Section 9);

h) material selections associated with hydraulic fracturing (see Section 10);

i) transportation of materials and equipment (see Section 11);

j) mobilization, rig-up, and demobilization (see Section 12);

k) storage and management of fluids and additives on-site (see Section 13);

l) management of solid and liquid wastes (see Section 14);

m) employee training (see API 75L);

n) job safety analysis (JSA).

These activities are likely to vary depending on the complexity, scope, and size of the project and are likely to evolve as conditions change. The items listed above should be re-evaluated to optimize environmental management. See 4.2 for more information.

4.2 Project Life-cycle Considerations

As part of project planning, operators should recognize that most, if not all, drilling, completion, and production activities will change as a project progresses from the exploration phase to the development phase to the production phase. Planning for several, isolated exploration wells has considerably different technical, environmental, safety, and business challenges compared to planning for an extensive multi-well, multi-location development program coincident with design and installation of centralized oil and gas gathering and processing facilities. Planning decisions should be appropriate for the phase of the project; however, operators should weigh the short-term benefits of planning decisions made during the exploration phase versus potential longer-term benefits of planning decisions that more readily accommodate project success and growth into the development and production phases.

Many of the project activities supporting drilling, completions and production will likely change out of necessity as the project grows from exploration to development and production. For example, a single local water source and off-site commercial waste disposal can be appropriate for an exploration well. Alternatively, plans during development may change to accommodate multiple water sources, including treated and reused water, and possible on-site waste disposal.

4.3 General Documentation

4.3.1 Documentation is a critical component of any well-planned and well-executed project. Operators should seek and follow legal advice to develop their document preparation and retention procedures.

4.3.2 General principles that apply to documentation processes include the following.

a) Retain final versions of documentation used in the preparation of permit applications, copies of permit applications, copies of approved permits, and any variances.

b) Retain final versions of documentation used in the preparation of reports in compliance with a permit or other regulatory approval. These may include environmental studies, consultant reports, laboratory reports, and professional or legal opinions.

c) Retain approvals of variances or waivers from regulatory requirements.

d) Retain documentation involved in any legal, regulatory, or compliance action.

4.3.3 Many regulatory agencies specify document retention requirements (including, but not limited to training records, inspection records, and plans, etc.) within their regulations or their permits and operators must comply with those requirements. For materials not directly addressed by such requirements, operators should seek legal advice regarding retention of materials.

4.4 Self-assessment and Follow-up

Operators should develop procedures for and implement routine walk-throughs and self-assessments of operations. These procedures should include tracking the findings to completion and resolution, documentation, and possible communication. The procedures may address the appropriate level of communication and document retention.

5 Site Selection and Considerations

5.1 General

The selection of a project area, and ultimately the well site, is an important step that can have implications for subsequent project stages. The examination of a particular project area should involve a thorough review of both short and long term factors related to operational, health and safety, land, infrastructure, logistical, and community considerations. In selecting a site, operator should consider suitability for drilling activities as well as future and ongoing production needs, and how the site will be integrated into existing or future field operations. Operators should also consider any environmental (sensitive habitat or protective species) and social aspects in site selection. A local evaluation of these factors should be made before a well site is selected. This may require on-site surveys as well as consultations with landowners and other local interests. The objective of this process should be to, as reasonably practicable, select project areas that promote successful and safe operations while reducing potential local disturbances.

Well pads should be planned with safety—worker, community, and environment—as a first priority. Site selection should also be made with an understanding of prevailing regulatory requirements, surface and mineral lease requirements, and subsurface geology in the area to the extent practical. Important factors in final site selection and potential impacts associated with certain locations may include: visual aesthetics, noise, vehicle traffic, emissions (dust and odors), lighting, erosion control, material use, existing land use and habitat, and management of hydrocarbons and produced water.

5.2 Site Plan

The site selection process should include an initial review of potential well pad locations by reviewing various public and private geographic information system (GIS) and mapping websites to evaluate major surface features, such as topography; water bodies and drainages; roads and other infrastructure; and current land ownership and use. Prospective well pad locations should also be investigated in the field by key project staff to confirm the site characteristics observed during the initial review and begin location design. In some jurisdictions, field reconnaissance of prospective well pads with federal, state, and/or local regulatory staff and/or the surface owner is required as part of the well permitting process. During the field reconnaissance, a general layout of the well site (well pad, ingress/egress, equipment location, impoundments, storage areas, etc.) can be staked and surveyed.

After the well pad location has been selected and surveyed, a site plan should be drafted for use by the project team in planning and permitting. The site plan should be used in developing other planning and operational documents.

5.3 Surface Considerations

5.3.1 Site selection for E&P activities warrants careful evaluation and planning to reduce surface disturbances. Larger well pads required for multiple wells and horizontal fracture stimulation, ultimately reduce the overall surface disturbance when compared to multiple single-well pads. These multi-well pads should be sized to accommodate the additional drilling and fracturing equipment and larger production facilities necessary for higher volumes of produced fluids. These larger well pads can result in additional localized impacts during construction, drilling, fracturing, well completion, and production operations that should be considered and mitigated as appropriate. As soon as practicable, temporary equipment can be removed and excess areas may be reclaimed, restored, or returned to other uses, reducing the location size and overall footprint. See API 51R for further information on appropriate reclamation practices.

5.3.2 In choosing a project area, operators should consider the following.

a) Encourage regional cooperation among operators to create plans for reducing surface disturbance (for example, developing shared infrastructure such as access roads, navigation channels, facilities, etc.).

b) Pre-plan and adequately size infrastructure and facilities to accommodate current and future production, to reduce disturbance at a location to a single occurrence.

c) Evaluate aspects and potential impacts of drilling multiple wells on a well pad.

d) Evaluate topographic, population, protected areas and hazards, zoning and other data to locate sensitive or high-exposure areas [such as churches, schools, hospitals, residential areas, surface waters, fresh water wells, flood zones, active fault areas, threatened and endangered plants and animals (including habitat), protected bird habitat, wetlands, archaeological, recreational, biological, or scenic areas]. Where feasible, the project area should be located away from these sensitive areas. This planning must comply with applicable regulatory setback and spacing requirements.

e) Use existing roads and rights-of-way to the maximum extent possible to also include pipelines, utilities, and other infrastructure. Where new infrastructure or pipelines may be needed, consider potential impacts of routes, property rights acquisition needs, and construction requirements.

f) Consult with the land owner and/or surface tenant to understand present and future uses of affected and adjacent land.

g) Reduce construction of facilities in floodplain areas. Certain jurisdictions have specific regulations regarding construction in floodplains and setbacks from water courses and water supply wells.

h) Reduce the amount of surface terrain alteration to reduce potential environmental and visual effects.

i) Reduce well pad locations requiring construction practices such as cut and fill in areas that can pose possible soil stability concerns and potentially increase stormwater run-on and run-off. Coverage under a construction stormwater permit may be required. Consideration should be given to stock-piling topsoil, if feasible. Subsurface soil conditions should be considered for adequate foundation support of the drilling rig, buildings, pumps, engines, tanks, and equipment used during hydraulic fracturing operations.

j) Position equipment and materials at the well pad to reduce the risk of spills migrating offsite and affecting soil, vegetation, and water.

Detailed guidance for site selection considerations is provided in API 51R.

5.4 Consideration of Visual Resources

5.4.1 General

Visually-significant resources designated through federal, state, and local processes are values shared by the general population. They include parks, historic places, preserves, refuges, landmarks, wild and scenic areas, etc. In addition to shared, visually-significant resources, local stakeholders value the natural beauty of the places where they live, work, and play. An operator should understand the potential impact from construction and operation activities and incorporate design and siting measures to reduce the potential visual impacts.

The visual impacts from operations at any particular site are generally minor and short-term, and vary with topography, vegetation, and distance to the viewer. Site-specific impacts can be greater with multi-well pads because the locations are generally larger than a single well pad, but the cumulative impact of a large-scale operation is reduced. Horizontal drilling provides flexibility to locate well pads in low impact areas and use of multi-well pads will reduce the visual impacts.

5.4.2 Design and Siting Measures

5.4.2.1 General

Design and siting measures are the simplest and most effective methods for avoiding or reducing potential impacts to visual resources. Operators should work with affected stakeholders to identify and/or map potential areas of high visual sensitivity and consider opportunities to reduce visual disturbance. Opportunities to reduce potential visual impacts can be incorporated into pre-construction planning, construction, and operational phases of the site. Design and siting measures can include screening, relocation, camouflage or disguise, low profile equipment, project scale, non-reflective materials, painting and color schemes, and lighting controls.

5.4.2.2 Screening

Screens are objects that conceal other objects from view. Screens may be natural or artificial and may be constructed of soil, rocks, bricks, or almost anything opaque. Vegetation can function as a screen when a sufficient density is employed. In natural settings it is generally better to employ natural materials, while in urban settings designers may employ a broader range of materials.

5.4.2.3 Relocation

A facility component may be relocated to another place within the site to take advantage of the mitigating effects of topography and vegetation.

5.4.2.4 Camouflage/Disguise

Colors and patterns of color can conceal an object or its identity and its disguise may take many forms. Painting and color schemes should blend with the existing areas. The use of non-reflective materials can reduce reflected light into surrounding areas.

5.4.2.5 Low Profile

Long-term facilities and equipment, such as tanks and compressors, should be placed to reduce potential visual impacts. Reducing the height of an object reduces its profile and visibility.

5.4.2.6 Project Scale

Downsizing/reducing the number, area, or density of equipment on-site can reduce their visibility.

5.4.2.7 Lighting

Lighting should be the minimum necessary for safe working conditions, security, and for public safety, and should be sited to reduce off-site light migration, glare, and sky glow light pollution. Mitigation should be considered when the impacts on receptors are significant and when such impacts cannot be avoided by design, scheduling, and siting measures. During night time operations, the use of barriers, such as wind walls, should be considered.

5.5 Noise Considerations

5.5.1 Noise is best mitigated by distance—the further from receptors, the lower the impact. The second level of noise mitigation is direction. Directing noise-generating equipment away from receptors greatly reduces associated impacts. Timing also plays a key role in mitigating potential noise impacts. Scheduling the more significant noise-generating operations during daylight hours provides for tolerance that may not be achievable during the evening hours.

5.5.2 Drilling and completion, including hydraulic fracturing, operations should be planned with these noise-related considerations. When possible, attention to the location of the access road may mitigate potential noise impacts associated with trucking and the hydraulic fracturing operations. When feasible, the well site and access road should be located as far as practical from occupied structures and places of assembly. Noise levels generated by vehicles depend on a number of variable conditions, including vehicle type, load, and speed, nature of the roadway surface, road grade, topography, and ground condition. Traffic noise mitigation measures may include modification of speed limits and restricting or prohibiting truck traffic on certain roads. Engaging stakeholders that can be potentially affected by noise impacts will result in nearby parties being better informed about the nature, character, and frequency of the noise disturbance.

5.5.3 Other examples of noise mitigation techniques that can be considered with regard to operations include:

a) placing tanks, trailers, topsoil stockpiles, or hay bales between the noise sources and receptors;

b) using noise reduction equipment such as hospital-grade industrial mufflers, exhaust manifolds, or other high-grade baffling;

c) properly maintaining equipment;

d) limiting operating hours of activities such as pipe cleaning, running casing, and laying down pipe to reduce disturbance to stakeholders;

e) locating or orienting high-pressure discharge pipes and other equipment away from noise receptors;

f) installing noise walls or noise barriers.

5.6 Road Use and Transportation Considerations

5.6.1 One of the main public concerns with large-scale operations is associated with the potential impact to public and private roads by vehicles supporting exploration, development, and production operations. The following should be considered to reduce road use impacts.

a) Review service rating [equivalent single axle loads (ESALs)] of roads that will be used in daily operations. Roads should be rated to accommodate the anticipated traffic to limit additional disturbance and new road construction.

b) Deliver source water and produced water through pipelines to reduce long-term use of water trucks.

c) Design and construct new roadways with potential impacts and purpose in mind. Consider sharing roads and infrastructure with other operators when feasible. Landowner input should be considered prior to construction as part of the planning process.

d) Maintain roads under either the operator's control or as required.

5.6.2 Road use and transportation issues are discussed in more detail in Section 11. In addition, detailed guidance for lease road planning, design and construction, maintenance and reclamation, and abandonment are also provided in API 51R.

5.6.3 One of the potential impacts is increased truck traffic to support high-volume hydraulic fracturing. Local authorities retain control over local roads and operators should determine if road use agreements and permits are required. Operators should develop a transportation plan that considers the following:

a) route selection to maximize efficiency and safety;

b) avoidance of peak traffic hours, school bus hours, community events, and overnight quiet periods;

c) coordination with local emergency management agencies and highway departments;

d) upgrades and improvements to roads to support the increased weight and use;

e) advance public notice of any necessary detours or road/lane closures;

f) adequate parking and delivery areas at the well site to avoid lane/road blockage.

5.7 Temporary Impacts

Temporary impacts such as dust, odor, and vibration during operations should be mitigated where practicable. In addition to the mitigation measures listed in 5.5, the following should be considered.

a) Dust—use, vehicle speed restriction, watering, non-toxic chemical stabilization, mulching, and vegetation rehabilitation to control dust deposition on adjacent vegetation, introduction into water bodies, and air quality impacts.

b) Odor—use closed tanks when practical; reduce volumes of vented gas; use natural gas engines in place of diesel engines, where feasible; discourage idling vehicles.

c) Vibration—use same actions identified for noise control (see 5.5).

6 Spill Prevention, Control, and Response

6.1 General

The best way to avoid the potential impacts of spills is to prevent their occurrence. Operations shall be conducted in a manner that reduces the potential for releases. To accomplish this, companies shall define spill prevention, control, and response procedures in their practices. These procedures should address the following topics:

a) transportation of materials;

b) primary and secondary containment measures;

c) operational procedures that reduce the potential for releases;

d) contingency procedures in the event a spill occurs;

e) training for well site personnel;

f) stormwater management and control.

Each of these topics is discussed in 6.2 through 6.7.

The use of non-fresh water including non-potable groundwater, treated and untreated waste water, and reuse of produced water can require additional precautions related to storage and transportation to reduce the potential of spills.

Companies also shall consider federal, state, and local regulations when developing plans. See API D16 for more information.

6.2 Transportation of Materials

Trucks and temporary piping are common methods for transporting equipment and materials. Materials must be loaded, transported, and unloaded in accordance with regulatory requirements and in a manner that is designed to prevent spillage. Temporary pipelines used to transport non-fresh water shall be designed, constructed, and operated to reduce potential piping failure and release of fluids into the surrounding environment.

Equipment transported over the highway and equipment used to transport materials shall be checked for leaks. Any open-ended lines should be properly capped before transport. Loads shall be properly secured and placarded. Containers, temporary piping, and other equipment shall be visually inspected for leaks. Discharge valves on tankers shall be inspected. Fresh water should be transported in dedicated tankers that have not previously carried other materials.

6.3 Primary and Secondary Containment

6.3.1 Impoundments can be used to store water for drilling, hydraulic fracturing, or to capture produced water. Impoundments must be designed and constructed to be fit for purpose and in accordance with regulatory requirements.

6.3.2 The following are additional design and construction practices for these storage facilities:

— liners for fresh water impoundments are not necessary unless required by local authorities or soil conditions;

— impoundments for non-fresh water (including produced water) should be lined with a natural or synthetic liner compatible with the material being stored;

— leak detection shall be incorporated into the design or operation of non-fresh water impoundments that will be in service for longer than one year;

— an impoundment's floor and interior slopes should be free of any sharp edges, rocks, and debris, to prevent liner failure;

— impoundments should be protected from stormwater run-off as described in 6.7.

Operators should perform and document routine visual inspections. As appropriate, corrective measures should be implemented and documented.

6.3.3 Hydrocarbons, produced fluids, additives, or other materials associated with well site activities must be managed according to regulatory requirements. Some fluids found at the well site are actively or passively managed to eliminate spills through the use of various containment methods, including those found in the federal spill prevention control and countermeasures (SPCC) requirements.

6.3.4 Material brought on-site (e.g. fuel, lubricants, additives) should be managed to prevent accidental release to the environment. These fluids can include both solid and liquid components. Primary containment methods commonly used include tanks, hoppers, blenders, sand separators, and lines. These primary containers should be visually inspected before and during an operation to assure integrity.

6.4 Operational Procedures

6.4.1 Spill Prevention Considerations

6.4.1.1 Key factors in spill prevention include planning and training. Operators should review well site and facility designs to determine where the potential for spills exists. Operators should periodically review prior spill incidents and recent facility modifications to identify where changes in equipment or operational practices may be needed. Using the results of the review, the following should be implemented, as appropriate.

a) Modifying the site layout or equipment/instrumentation installation or removal as needed to reduce the potential for spills. Consideration should be given to the use of alarms, automatic shutdown equipment, or fail-safe equipment to prevent, control, or reduce potential spills resulting from equipment failure or human error.

b) Having a maintenance and/or corrosion abatement program to provide for continued sound operation of equipment.

c) Inspecting and/or testing of lines, vessels, dump valves, hoses, and other pollution prevention equipment where failure(s) and/or malfunction(s) can result in a potential spill incident.

d) Operating procedures that reduce the risk of spills. These operating procedures should be documented and communicated to operating personnel.

e) Examining drainage patterns around a well site or facility and installation of containment, best management practices (BMPs), barriers or response equipment, as deemed appropriate.

6.4.1.2 Additional planning and/or controls can be necessary in cases where a well site or facility is located:

a) near a designated sensitive environment or habitat;

b) near a designated groundwater aquifer recharge area or surface waters (such as lakes, streams, springs, ponds, wetlands, floodplains, etc.);

c) near potable water sources or agriculture/livestock water sources;

d) near occupied buildings; or

e) in an area known for unstable soil or naturally-unstable construction conditions.

6.4.2 Job Safety Meeting

Prior to job execution, operators should consider conducting a job site safety meeting with site personnel to confirm that the personnel performing and supporting the fracture operation understand their responsibilities and recognize potential environmental and safety concerns associated with operations. Recommended discussion topics for this meeting include the following.

a) Job tasks and inherent risks.

b) Spill prevention and response measures for any equipment or material that is brought onsite or managed.

c) Awareness that spilled materials shall be cleaned up, managed and disposed or reused in an approved manner.

d) Familiarity with the materials and awareness of the Safety Data Sheet (SDS) for each additive on site. The SDSs are readily accessible.

e) Information on personal protection equipment (PPE), emergency and first aid procedures.

f) Operator and/or contractor procedures and response plans to properly manage, reuse, or dispose of waste generated.

g) Procedures to report leaks or spills to the on-site manager, appropriate operator manager and personnel, and regulatory agencies (the information should include the material spilled, the SDS for the material, the location of the spill, the estimated amount of the material that was spilled, and the response action taken and planned).

6.4.3 Equipment Fueling Operations

Equipment fueling operations should be planned and conducted to reduce the potential for spillage. Operators and contractors should:

a) review the spill prevention procedures (see 6.4.1) prior to initiating operations;

b) consider the use of portable containment equipment;

c) have appropriate and sufficient amounts of sorbent materials (spill kits) readily available on the well site to provide for an initial response to a spill, until additional equipment and material can be mobilized;

d) develop and communicate methods to monitor fuel transfer hoses, use hose/nozzle covers, and monitor fuel transfers for system integrity before, during, and after fueling operations; and

e) have an attendant present to monitor fueling operations; and

f) avoid fueling during on-going operations, unless a risk assessment has been conducted.

6.4.4 Housekeeping Practices

A clean, well-organized work site is indicative of good planning and efficient job execution. Implementing good housekeeping practices also play a vital role in reducing environmental and safety incidents. Generally, good housekeeping practices can reduce the risk of injuries, spills, releases, or worker exposure to materials. The following good housekeeping practices apply.

a) Spilled solid materials or free fluids should be removed as soon as practical.

b) Contaminated materials and used absorbents should be placed into appropriate containers, labeled, and stored until properly disposed.

c) Trash and debris should not be allowed to accumulate. Regular site inspections should be conducted and discarded material and rubbish should be collected and properly contained until it can be disposed.

d) Piping, tubing, and power cords should be placed so as to prevent tripping or entanglement hazards. Conduits or bridges should be used where practical.

e) Efforts should be made to store only enough materials required to do the job.

f) Materials kept on-site should be stored in a neat, orderly manner in their appropriate containers.

g) Solid materials should be protected from the weather and liquid containers should be kept in secondary containment where possible.

h) Materials shall be kept in their original containers with the original manufacturer's label.

i) Manufacturers' recommendations for proper use and disposal of materials should be followed.

j) Whenever possible, materials should be completely dispensed before disposing of the container.

k) On-site vehicles and equipment should be monitored for leaks.

l) The hazards of mixtures or dilutions should be considered.

The use of techniques such as sloping the ground surface around the well pad away from surface water locations, positioning absorbent pads between sites and surface waters, perimeter trenching systems, and catchments may be used to contain and collect any spilled fluids.

6.5 Contingency Procedures

6.5.1 Operators should develop controls and planning procedures with consideration of the well site or facility location. Operators should also engage emergency responders in local communities to raise awareness of potential hazards; discuss response coordination, reporting and clean-up; and discuss contingency measures.

6.5.2 Individuals responding to a spill should be properly trained in spill response and mitigation. The source of the spill should be isolated, controlled, and/or reduced to the extent possible, in a safe manner. Methods to control and contain spilled substances include the following:

a) retaining walls or dikes around tanks;

b) flow diversion structure;

c) secondary catchment basins designed to prevent the spread of fluids that escape the primary wall or dike;

d) absorbent pads;

e) booms in water basins adjoining the facility;

f) temporary booms deployed in the water after the spill occurs;

g) use of special chemicals to gel or biodegrade the spilled fluids. Use of special chemicals may require approval.

6.5.3 Operators must prepare remediation plans in accordance with the regulations and landowner agreements in the case of a spill.

6.6 Training for Well Site Personnel

Operators should verify that employees or contractors responsible for spill prevention and management have been trained in the duties they will perform. The level of training may vary based on the duties and responsibilities of an individual. Training should include, but is not limited to, the following:

a) applicable environmental and spill prevention laws, rules, or regulations;

b) regulatory or operator-specific plans;

c) hazard communication;

d) operation and maintenance of equipment or measures used to prevent or respond to a spill;

e) emergency response, reporting, and investigation;

f) regional characteristics or site-specific details that should be considered during a spill response;

g) records retention.

6.7 Stormwater Management and Control

6.7.1 Operators should consult IPAA's guidance document titled, *Reasonable and Prudent Practices for Stabilization (RAPPS) at Oil and Natural Gas Exploration and Production Sites* [28], that describes various operating practices and control measures used by oil and natural gas operators to effectively control erosion and sedimentation in stormwater runoff from clearing, grading, and excavation operations at exploration, development, and production-sites under various conditions of location, climate, and slope.

6.7.2 Stormwater runoff can occur from precipitation events. Operators shall conduct stormwater management planning. Operators should prepare a stormwater management plan (SMP) in accordance with applicable regulatory requirements during project design. The SMP should be site-specific and prepared prior to commencement of construction activities. Additionally, the SMP should be updated if there is a change at the construction site affecting the discharge of pollutants or if plans prove ineffective at controlling the discharge of pollutants. In the absence of regulatory requirements, operators should evaluate site-specific conditions and consider implementing BMPs as warranted.

6.7.3 An operator should verify that personnel involved with construction activities have been trained on stormwater management procedures before assigning them to these duties. When appropriate, contractors should provide documentation of stormwater training or any other training required in procedures.

6.7.4 An operator should consider a variety of factors in the development of a SMP, including the protection of endangered and threatened species, critical habitats, dwellings, and historical properties. Also, natural drainage patterns of the area should be considered in the location of equipment, pads, and impoundments so that stormwater runoff does not erode base material, which can lead to equipment instability, or adversely impact impoundments, potentially causing a discharge of fluids into local surface waters. Stormwater collected in secondary containment structures should be inspected and documented for signs of contamination prior to discharging.

6.7.5 Site construction should be inspected on a routine basis and following each significant storm event. Repairs to the control systems should be completed promptly. During the drilling and completion phases, the site should be stabilized and raw materials should be stored in a manner to prevent the contamination of natural runoff.

7 Logistics

Operators should consider relevant logistics during the planning stage to facilitate effective scheduling and timely execution of phases of development. Factors to consider in logistics planning include the following potential impacts on the community and infrastructure:

a) area workforce and support personnel;

b) local accommodations;

c) emergency and medical response capabilities;

d) area economics, such as real estate markets and other business developments;

e) contractors and equipment;

f) municipal services;

g) roads and utilities;

h) housing, schools, restaurants, hospitals, fuel and food supply.

See API 100-3 for engaging the community and disseminating information on potential activities.

8 Baseline Groundwater Sampling

8.1 General

8.1.1 This section provides technical guidance only, and practices included may not be applicable in all circumstances. Given the potential for regional, geologic, or other variations, deviations from this recommended practice can be expected. The operator is responsible for contract terms and negotiations, acquiring proper authorization to perform sampling, determining compliance with applicable regulatory requirements, and seeking legal advice when needed.

8.1.2 The operator should understand the groundwater conditions in their area of operations. A baseline sampling program can help establish conditions at the time and location of sampling that can be useful in assessing the nature and extent of potential future change. Operators should be aware that natural variation and fluctuations in water chemistry will occur over time and should be considered when developing a baseline sampling program or interpreting sampling results. A baseline sampling program can vary, from a modest program focused on single, isolated exploration wells, to a comprehensive, field-wide program suited for a multi-well, multi-location development project.

8.1.3 In many areas existing data may be available to provide a representative characterization of groundwater resources. Operators should be familiar with these existing data resources [e.g. regional water management districts, state environmental agencies, Environmental Protection Agency (EPA), U.S. Geological Survey (USGS)] when assessing the need or value of offering additional sampling. Factors that can be considered when deciding to do additional sampling can include the following:

— area and depths covered by the existing data relative to the operator's well site;

— parameters that are monitored and their associated spatial and temporal variability;

— frequency, analytical methods used, and age of available data;

— applicable legal conditions (presumption of liability) or regulatory requirements.

8.1.4 Where sufficient data are not available, the operator should consider a baseline sampling program. When an operator elects to perform groundwater sampling, the approach taken here should be considered to develop a baseline data set. This guidance provides a framework to establish existing aquifer conditions in order to discern changes in conditions that can potentially occur as a result of drilling and completions activities.

8.2 Scope of Sampling Program

8.2.1 Water Sources to be Sampled

Baseline water sampling is conducted primarily to characterize preexisting groundwater conditions. An operator should consider local water uses when identifying the sources to be sampled. In addition to groundwater, the operator may choose to sample surface water sources if local conditions warrant such an approach.

8.2.2 Number and Location of Wells Sampled

The number of water wells to be sampled should be based on the location of the oil and gas well(s) to be drilled, and the local hydrogeological environment. The sample(s) should be representative of the groundwater quality at the oil and gas well location.

The operator may also opt to sample the rig supply well at or near the well site. Many state or regional jurisdictions require sampling of water wells, which can provide valuable historical information and also affect the baseline sampling program developed by the operator.

Sampling locations or timing may be restricted based on the operator's lease or access rights, or availability and quality of information. The following factors should be considered:

a) location of water well(s) relative to the groundwater flow gradient;

b) depth of water well(s) to be sampled;

c) distance from the proposed well or facility;

d) water well construction;

e) well density within the area of interest;

f) inventory of potential water users;

g) site-specific hydrogeology;

h) proximity of receptors.

8.2.3 Sampling Frequency

If the operator is conducting baseline sampling, it should be completed prior to and as close to initiating operations, as practical. The operator may consider taking follow up samples to better assess the nature and extent, if any, of potential changes or natural variations in water quality.

8.2.4 Sampling Methods and Analytical Parameters

The personnel collecting the baseline samples should be trained and familiar with proper protocols for sample collection and handling. Similarly, the analytical laboratories should be accredited through the applicable government and accreditation agencies to perform the required analyses. The sampling and analytical methodologies established by the appropriate regulatory authority must be followed. Samples, including QA/QC samples (e.g. field blanks and spike duplicates), should be collected, analyzed, and documented (e.g. chain of custody, QA/QC protocols in the field and in the laboratory) in accordance with regulatory and accepted industry practices (e.g. *EPA Field Sampling Procedures for Groundwater*).

The recommended analytical parameters are intended to cover basic cations and anions, common naturally-occurring constituents, as well as indicator constituents that can be found in hydraulic fracturing fluids or produced water. Specific dissolved gases should be analyzed to determine the baseline characteristics of those gases.

The operator should select an analytical method based on an evaluation of the sensitivity of that method, the data quality objectives, and the media being sampled. Most analytical methods for measuring constituents in water are described in 40 *CFR,* Part 136. For non-aqueous media (e.g. head space gas), other methods may be appropriate.

8.3 Parameters

Based on industry experience when conducting sampling and analyses, the following parameters should be considered.

NOTE Some of the parameters listed may not be related to oil and gas activities and are included to provide a general characterization of groundwater conditions.

a) Laboratory parameters as follows:

— benzene, toluene, ethylbenzene, xylenes (BTEX);

— total petroleum hydrocarbons;

— sodium absorption ratio (SAR);

— total dissolved solids (TDS);

— potassium;

— chloride;

— bromide;

— arsenic;

— barium;

— calcium;

— magnesium;

— sodium;

— alkalinity (bicarbonate/carbonate);

— lead;

— boron;

— iron;

— manganese;

— sulfate;

— methanol;

— light hydrocarbons (methane, ethane, propane);

— total coliform.

b) Field measurement parameters as follows:

— pH;

— conductivity;

— turbidity;

— oxidation-reduction potential;

— temperature.

c) Other parameters, based on local area conditions and regulatory requirements.

8.4 QA/QC Samples

Quality Assurance/Quality Control (QA/QC) samples should be collected as part of a baseline sampling program to provide a higher level of confidence regarding the validity of the analytical results. Where available, the QA/QC methodology established by the appropriate regulatory authority should be followed. A typical QA/QC sampling protocol can include collection of blind duplicates, matrix spike duplicate, matrix spike/matrix spike duplicate (MS/MSD) samples, trip blanks, and field blanks.

8.5 Additional Sampling and Analyses

If sufficient concentrations of dissolved hydrocarbon gases are detected, the operator may choose to perform additional analyses (fingerprint) to identify the potential sources or origins of these gases. Typically, this would be accomplished with isotopic analyses of the carbon and hydrogen found in the gases. The isotopic analyses, along with additional information such as local geology, neighboring land usage, etc. can help determine the nature and source of the dissolved gases.

9 Source Water Management

9.1 General

9.1.1 Water is used in E&P activities, including drilling operations and well stimulation activities. In general, hydraulic fracturing methods will proportionately use more water than other E&P uses. It is important to consider these recommended practices as early in the project planning as possible. Recommended practices for transport, storage, use, and disposal are discussed in other sections of this document. Treatment design is outside the scope of this document.

9.1.2 Water is the base fluid for most hydraulic fracturing fluids and can comprise over 90 % (by volume) of the pumped fluid. Section 10.3.2 discusses other base fluids used for hydraulic fracturing.

9.1.3 Operators should consider the full life-cycle of water and the project. The following factors should be considered during planning for water acquisition, use, and management in hydraulic fracturing operations.

a) Source water requirements: consult with drilling and completions staff to identify the acceptable water quality characteristics. Obtain estimates of water quantities required to meet the short-term needs of individual wells, and evaluate the longer-term needs of the project (see 9.2.1 and 9.2.2).

b) Acquisition: identify potential available water supplies, including produced water, in proximity to specific well pads and the project area. Evaluate the suitability of the potential water supplies available. Characterize the chemical and biological quality and estimate the quantity of the different available water sources. Identify potential competing local users and water needs, both existing for short-term activities and future for long-term activities (see 9.2.2 and 9.2.3.1).

c) Transport: identify potential opportunities for transportation of the water from the available source(s) to the well pads or centralized storage and distribution facilities. In some cases, produced fluids from the well pads can also be transported to the point of treatment by the same means (see Section 11).

d) Storage: identify the requirements and constraints for constructing and operating water storage on well pads and centralized facilities. Drilling and hydraulic fracturing fluid requirements and operating practices can influence the nature and use of storage facilities (see 14.2).

e) Use: identify the potential composition of the drilling fluid or hydraulic fracturing fluid. Understand the volume of the water to be used, the nature of proppants and other additives, and the process for blending and injecting fluids to achieve the hydraulic fracturing objectives. Depending on the nature of the water source, water treatment (i.e. pre-treatment) may be required before use (see 9.2 and 9.3).

f) Treatment and reuse: evaluate the produced water for possible treatment and reuse. Various water treatment options exist that can economically remove chemical and petroleum constituents, and solids from produced water, allowing the fluids to be used in subsequent hydraulic fracturing operations. After treatment, the produced water may be reused or blended with additional water supplies to prepare additional hydraulic fracturing fluids (see 9.2.3.4, 9.2.3.5, and 14.2.3).

g) Disposal: if the produced water is not to be treated and reused, evaluate options for disposal (see 14.2.4).

9.2 Evaluate Source Water Requirements

9.2.1 General

Source water quality and quantity requirements will vary depending on the geologic and reservoir conditions anticipated, as well as the nature and extent of the exploration, development, or production phases of the project. During the exploration phase, relatively small volumes of water are typically required proportional to the limited number of wells that are drilled and completed. Development activities are characterized by extensive construction, drilling and completion activities, including hydraulic fracturing. Of these development activities, hydraulic fracturing typically results in the most significant water use. As development activities progress, the operating wells may generate sufficient produced water to warrant consideration of treatment and reuse of these fluids in the development activities. In the event that produced waters are reused, the volume of "new" water needed to continue development activities can be reduced. As development activities near an end, water use gradually declines. Water use during production activities continues to decline, typically limited to maintenance and operations only.

Water sources used during the early, short-term phase of the project (i.e. exploration phase) may not be sufficient for the long-term phases, when full scale development and production is undertaken. During full-scale development and production, water acquisition may include obtaining water from multiple sources of varying quality and quantities. After development has concluded and full scale production is proceeding, the number of water sources and water used should decline significantly.

9.2.2 Water Quantity and Quality Requirements

In evaluating source water requirements for hydraulic fracturing, the operator should conduct a comprehensive evaluation of cumulative water demand on a programmatic basis, as well as the timing of these needs at an individual well site. This should include consideration of the various water quality and quantity requirements for construction, drilling operations, completion operations, dust suppression, and emergency response, along with the water requirements for hydraulic fracturing operations. The operator should determine whether or not the sources of water are adequate to support the total operation.

Water supply options for hydraulic fracturing operations will depend on:

a) amount of water and the proximity of the source to the well pad;

b) land use and access;

c) planned pace and level of development anticipated for the long-term, area-wide program;

d) an analysis of the site-specific and regional water supplies;

e) potential competing user demands;

f) climatological, and hydrologic/hydrogeologic conditions of local resources, such as water resources reports and water supply forecasts, including seasonal variations;

g) specific fluid design, based on source water quality, reservoir characteristics and targeted hydrocarbon resources.

See API 100-1 for more information on well construction and fracture stimulation design and execution.

The fluids produced during hydraulic fracturing should be considered for reuse in subsequent hydraulic fracturing activities depending on the quality and quantity of those fluids. See Sections 10 and 14.2.3 for more information on hydraulic fracturing fluid design and specification, use and reuse, respectively.

9.2.3 Potential Water Sources

9.2.3.1 General

9.2.3.1.1 Operators should coordinate their operational plans with their anticipated water use and available supplies identified during the early project planning. The potential effect of additional fresh water demand on the local community and region should be considered.

9.2.3.1.2 Sources of water can differ significantly from region to region. Alternative sources of water such as brackish, saline, produced, and third party waste water have been used successfully in onshore operations. In addition, operators have successfully used seawater in certain offshore applications and should consider the possibility for applications in coastal onshore operations. Readily accessible information exists to develop a comprehensive picture of available sources of usable water. Sources of information can include government agencies, non-government organizations, academic institutions, and industry partners.

9.2.3.1.3 Local water use for agriculture, manufacturing, municipal public supply, recreation, or other uses should be considered when evaluating sourcing needs. Seasonal changes in both water demand and availability are also an important factor to consider.

9.2.3.1.4 Competing demand on any one water source can lead an operator to consider alternate water sources, and/or consider combining different water sources. Existing information from regulatory agencies, such as a water development board, water use/management districts, city public works departments, etc., can be used to identify potential competing uses for water. Local agencies can also be helpful for identifying where potential industrial sources have return requirements as part of their use permits; this restriction can limit or eliminate the use of third party waste water as source water. Operators should consider not only the actual effects of their activities on the local and regional water supplies and delivery systems, but public perception of the operator's use of water, and potential effects to local and regional infrastructure for their exploration, development and production. API 100-3 outlines stakeholder engagement processes for addressing such public concerns.

9.2.3.1.5 Water for hydraulic fracturing can originate from various sources, including:

a) surface water (fresh water);

b) potable groundwater (shallow fresh water);

c) non-potable groundwater (deeper brackish and saline water);

d) treated and untreated waste water from municipal and industrial sources; and

e) produced waters from hydraulic fracturing and oil and natural gas production.

9.2.3.1.6 Water can be obtained from various federal, state and local entities, including:

a) private third party individuals and companies by contractual agreements;

b) operator-developed water secured by water rights obtained per state regulatory requirements;

c) federal and state water agency programs and projects;

d) private water companies (including co-ops);

e) agricultural water users;

f) municipal water suppliers and rural water districts;

g) industrial suppliers (e.g. power plant cooling water, mine dewatering water, etc.); and

h) produced water from oil and gas well operators.

9.2.3.1.7 Obtaining or acquiring water from any of the entities listed in 9.2.3.1.6 may require conversion of the current designated water use, either temporarily or permanently, to industrial use per regulatory requirements. Water sources and water providers can vary over the life of the project (exploration, development, and production), to meet the economic and technical needs of the project.

9.2.3.1.8 Site-specific volume and water quality requirements, regulatory limitations, physical availability, competing uses, drilling requirements, and characteristics of the formation to be hydraulically fractured (including water quality and compatibility considerations) will ultimately determine the water sources available for use. Any treatment to meet water quality needs can require additional waste management. The quality of the source water also can affect the performance of the additives that will be needed for the operation. See Section 10 on material selection.

9.2.3.2 Surface Water

9.2.3.2.1 The operator should identify water supply sources that are capable of meeting their needs while reducing the impact on community needs and other uses. Important considerations in evaluating surface water sources include the following:

a) seasonal variability of supply and demand;

b) water rights and permit requirements from regulatory agencies;

c) surface water withdrawal permits are likely to specify compliance with specific metering, monitoring, reporting, record keeping, and other consumptive use requirements;

d) landowner contractual agreements;

e) water withdrawal limitations because of potential effects on other uses during periods of low stream flow;

f) potential short term and cumulative environmental and community impacts;

g) potential hydrologic impacts in shallow aquifer discharge/recharge zones;

h) transport and storage requirements.

9.2.3.2.2 In addition to the regulatory requirements, agencies, local communities, and other stakeholders can have additional concerns about potential effects to the area. API 100-3 outlines stakeholder engagement processes for addressing these concerns.

9.2.3.2.3 Management practices to reduce potential seasonal effects on municipal drinking water supplies and aquatic habitats include the following.

a) On-site or centralized storage ponds. Operators should be aware of any state and/or local engineering design and permitting requirements, and construction standards for reservoirs and impoundments that will need to be met.

b) Use of multi-well pads encourages the use of central water storage facilities, reduces truck traffic, and allows for more efficient and centralized management of produced water. In some cases, multi-well pads also enable the option of pipeline transport of source water and produced water. Section 13 outlines storage alternatives available for managing water, hydraulic fracturing fluids and produced water.

c) Harvesting rain water depending on local precipitation rates, available storage, and the amount of time needed to capture sufficient rain. Operators should be aware of any applicable regulatory requirements or prior appropriated water rights.

9.2.3.3 Groundwater

Operators may need to address many of the same types of considerations for groundwater as for surface water, such as water rights and permit requirements from regulatory agencies. The primary concern regarding groundwater withdrawal is potentially affecting current, permitted water users. Operators should consider water rights and permit requirements for acquisition of groundwater and whether there are limitations or other restrictions on withdrawal rates.

Operators should consider using non-potable groundwater for drilling and hydraulic fracturing operations. The use of non-potable sources may require different fracturing fluid formulations and can alter the efficiency of the composite fluid.

Operators should consider the location of municipal, public, industrial or private water supply wells when selecting a water source well site. Withdrawals from groundwater, especially USDWs, typically require permits from regulatory agencies. In some cases, operators can contract with private third party land and water owners to withdraw groundwater without new permitting requirements.

Advances in hydraulic fracturing fluid formulations increasingly allow the use of base fluids with increased TDS concentrations. Groundwater with elevated TDS concentration can be developed from aquifers typically geologically-isolated beneath freshwater aquifers. The quality of the groundwater varies by hydrogeologic basin and the nature of the specific aquifer materials. Groundwater from some aquifers can require treatment before use.

9.2.3.4 Treated and Untreated Waste Water from Municipal and Industrial Facilities

Municipal waste water, industrial waste water, and/or power plant cooling water are other possible alternative water sources to support hydraulic fracturing operations. Users of waste waters will need to comply with the state and federal regulatory requirements associated with the reuse of municipal and industrial waste water. Municipal and industrial facilities can be limited in their ability to provide water for hydraulic fracturing operations if their use permit requires return flows back into its water source. In some cases, required water quality and quantity specification can be achieved by combining different water sources.

9.2.3.5 Produced Water Reuse

Produced water from oil and gas wells may be treated and reused for hydraulic fracturing, depending on the chemistry of the water and the logistics of the well pad and hydraulic fracturing operations. Both hydraulic fracturing fluids and formation water contribute to the chemical characteristics of the produced water. The overall quality of this produced water mixture can vary by geologic basin and specific rock strata. In situations where produced water is treated and reused, additional make up water can be required. Section 14 outlines additional information on treating produced water.

9.3 Develop Water Sourcing Plan

9.3.1 Considerations for Prioritizing Water Sources

Water source options listed in the previous sections may not be available for all situations, and the order of preferences can vary from area to area. As a contingency, operators should consider securing at least one alternative water source in the event that the primary water source is interrupted or terminated. Operators should consider treatment requirements of alternative water sources.

The prioritization of primary water sources will depend upon volume and water quality requirements, regulatory requirements, physical availability, competing water uses, and characteristics of the formation to be hydraulically fractured (including water quality and compatibility considerations). If possible, waste water from other industrial facilities and produced water should be considered first, followed by ground and surface water sources (with the preference of non-potable sources over potable sources), with municipal water supplies generally being the least sustainable (at least for long-term development and production). However, this ranking will depend on the availability of ground and surface water resources in proximity to planned operations, and local hydrologic and hydrogeologic conditions.

9.3.2 Securing Source Water

9.3.2.1 General

Operators should secure both primary and contingency water sources depending on the scale of their projects. At project initiation, reliable water sources are needed to assure timely execution of well drilling and completion. Water supplies are typically acquired through state and local regulatory permit processes and/or contractual agreements with third parties.

9.3.2.2 Regulatory Requirements

Regulatory requirements often dictate water management options. These include federal, state and local regulatory authorities. Along with these regulatory authorities, multi-state and regional water permitting agencies may also be responsible for maintaining water quality and supply. State, federal and local agencies and authorities can restrict water sources and volumes withdrawn and/or disposal options that are available for consideration and use. Some governmental entities have the authority to change water rights priorities in times of drought or other emergencies. A report prepared for the U.S. Department of Energy provides a comprehensive, practical guide of state oil and gas regulations designed to protect water resources [27].

9.3.2.3 Contractual Agreements

Water supplies can be purchased from various third parties, including land owners, municipalities, and local water agencies. Terms and conditions in contractual agreements should be developed and reviewed by attorneys familiar with water sale and use agreements, and state and local water laws and regulations. When the water supply is from a private source, additional requirements can be requested by the landowner or private party through contracts or negotiated agreements. Regulatory authorities can also have specific contractual requirements. These requirements should be carefully considered since regulatory agency and/or landowner requirements can be the controlling factor(s) in the availability and delivery of water.

9.3.3 Considerations for Water Management Plan

9.3.3.1 Operators should develop a water management plan for any project, regardless of scope and scale, including both short term and long term supplies, primary and contingency sources. The complexity of the water management plan should be commensurate with the drilling and completion program. Depending on the anticipated need for water, operators should evaluate and take action to obtain water rights if applicable to the area.

9.3.3.2 A comprehensive water management plan document can be appropriate for larger projects. An example water management plan is outlined below:

I. Executive Summary

II. Business Unit and Regional Water Risk Assessment

III. Regulatory and Legal Framework

IV. Water Source requirements—Demand Summary

   a) Operations and development plan for defined area

   b) Drilling and completions, hydraulic fracturing

c) Other water uses

d) Include timing, especially critical path

e) Quality requirements

f) Competitor demands and timing—summary of regional demand

V. Potential sources—Supply Availability and Acquisition, (e.g. Water Rights and Water Use Permits):

a) Surface water

b) Groundwater- fresh and saline

c) Municipal water

d) Municipal and other waste water

e) Reuse

VI. Stakeholder Concerns and Issues

a) Landowner agreements and restrictions

b) Water Purveyor agreements and restrictions

c) Public issues and concerns

d) Stakeholder engagement/communication issues

VII. Transportation and Storage Options and Evaluation

VIII. Disposal Alternatives and Evaluation

a) Matrix of potential options

b) Selected alternatives for evaluation

IX. Documented Strategy and Action Plan

a) Life cycle evaluation (including costs, reliability, sustainability, potential environmental effects, stakeholder effects)

b) Rationale for selected alternative(s)

c) Contingency plans

d) Detailed action plan to ensure identified water risks and objectives are addressed

9.3.3.3 While the regulation and control of water use varies regionally, organizations such as groundwater conservation districts, water development boards, and river commissions are potential sources of information for developing such a plan. Often these organizations prepare regional water development and/or use plans to aid in promoting municipal and industrial growth while protecting the environment. State agencies responsible for oil and gas regulation can also have information on wells that are planned or have been permitted for a given area. Such information can also prove useful in developing a water management plan. Water source planning should consider community/stakeholder engagement activities. API 100-3 outlines stakeholder engagement processes applicable to this effort.

10 Material Selection

10.1 General

Hydraulic fracturing materials can include fracturing fluids, additives, and proppants. This section describes methods to reduce the potential environmental impact of hydraulic fracturing materials through:

— selecting materials with reduced environmental profiles; and

— reducing the quantity of materials used.

A general description of additive categories are included in Annex A. Reducing potential environmental effects of materials used requires proactive discussions between operators and contractors to identify alternate chemistries that achieve fluid performance requirements.

Reduction of quantity of materials used relies on operators and contractors to work together to identify the optimum amount of material needed to complete the well. Different completion alternatives should be evaluated based on knowledge of the reservoir and offset wells, which may include petrophysical and geomechanical models to identify the required amount of materials. This may necessitate taking measurements such as production performance, logs, cores, or drill cuttings to create and calibrate these tools.

10.2 Selection of Hydraulic Fracturing Fluids

The fracturing fluid is an important element of the hydraulic fracturing treatment. The fluid's main functions are:

— to open the existing natural fractures or create new fractures;

— to transport proppant into the fracture; and

— to keep the fracture open until the pressure is released.

Because of their wide availability, ease of handling and high performance, water-based fluids are the most commonly used hydraulic fracturing fluid. In geologic formations where stress anisotropy is low, complex hydraulic fractures are likely to form and low viscosity slickwater fluids have been applied with successful results [22]. In geologic formations where stress anisotropy is high, more planar hydraulic fractures are likely to form and high viscosity fluids have been applied with success [23].

The volume and composition of fracturing fluids should be selected based on a wide variety of factors. For example, the composition and required volume of hydraulic fracture fluids to be pumped will vary by geology, productivity, number of stages, and wellbore length, while achieving controlled fractures within the target formation. As projects progress from the exploration phase to the development and production phases, the "lessons learned" from each preceding well may suggest changes to the composition and volume of hydraulic fracturing fluids used until an optimal hydraulic fracturing program is developed for the project area.

10.3 Materials used in Hydraulic Fracturing

10.3.1 General

The fracturing fluid is a carefully formulated product. The design and composition of the fluid varies based on the characteristics of the well, reservoir formation, total system compatibility, quality of the base fluid, and specified objectives. Situation-specific challenges include: scale buildup, bacteria growth, proppant transport, iron content, fluid stability, and breakdown requirements.

Addressing each of these criteria may require specific additives to achieve the desired well performance; however, not all wells require each category of additives. Furthermore, while there are many different formulas for each type of additive, usually only one or a few of each category is required at any particular time.

The formulation of a fracturing fluid is complex and the process is often iterative. As experience and reservoir knowledge increase, the required number of additives and their concentrations generally decrease over time.

There are three primary material types used in hydraulic fracturing fluids, as discussed in 10.3.2, 10.3.3, and 10.3.4.

10.3.2 Base fluid

Water is the most common base fluid component for most hydraulic fracturing treatments, representing the vast majority of the total volume of fluid injected during fracturing operations. Alternative base fluids may be considered when reservoir characteristics dictate.

If a reservoir has low pressure, a gaseous base fluid may be preferred to provide sufficient energy to properly lift and clean up the fracturing treatment. Some types of alternative fluids include nitrogen, liquid petroleum gas (LPG), or carbon dioxide.

If an oil and gas reservoir is known to be sensitive to water, alternative base fluids may be employed to reduce the interaction between water and the reservoir, such as utilizing lease crude or LPG-based fracturing fluids. If hydrocarbon-based fluids are planned to be used, the operator is responsible for obtaining the proper permits from the appropriate regulatory authority.

10.3.3 Proppant

10.3.3.1 General

Proppant is an important element of the hydraulic fracturing treatment. The main objective of the proppant is to maintain the open fracture and to provide a relative highly conductive flow path from the reservoir to the wellbore. Most proppant is transported to the well site in trucks, transferred pneumatically to storage bins and added to the fluid stream through a system of conveyor belts, augers, and gates.

There are several classes of proppant typically used in hydraulic fracturing treatments depending on desired conductivity and geologic stresses.

a) Sand is the most commonly used proppant as it is widely available and can withstand stresses up to 6000 psi (41.4 MPa). Sand includes silica-based natural materials.

b) Resin coated sand (RCS) is sand coated with a resin compound. The coating provides additional stress resistance up to 8000 psi (55.2 MPa), reduces proppant flowback and traps fines resulting from crushing.

c) Intermediate strength proppant (ISP) is proppant manufactured generally from ceramic-based materials and can withstand stresses up to 10,000 psi (69.0 MPa).

d) High strength proppant (HSP) is proppant manufactured generally from sintered bauxite and can withstand stresses up to 15,000 psi (103.4 MPa).

10.3.3.2 Silica Dust

Airborne silica dust can be generated from sand handling operations that occur during the hydraulic fracturing process. Operators should verify that sand is transported in enclosed tanks or containers. Operators should evaluate the potential for silica exposure at their operating sites, and if warranted, consider using dust control measures such as water sprays, shrouds, tarps, and dust collection equipment during sand transfer and handling activities. Personnel must have access to appropriate PPE in accordance with regulatory requirements.

10.3.4 Additives

Additives used in the process of hydraulic fracturing typically represent less than 2 % of the volume of the fluid pumped during a hydraulic fracturing treatment [24]. Additives can include polymer, friction reducers, crosslinker, breakers, bactericides, surfactants and many others. These additives, along with the characteristics of water in the formation being fractured, affect which management and treatment options are applicable to the produced water [26].

A variety of factors including source water chemistry, formation lithology, and formation fluid compatibility will impact the additive performance to achieve the required functions. A selection of additives that can be considered are discussed in Annex A.

11 Transportation of Materials and Equipment

11.1 Transportation Planning

11.1.1 General

Transportation of materials to the site, including water, additives, and equipment, should be carefully planned. Operators can use several strategies in these types of activities to improve efficiency and reduce risks. When making transportation decisions, operators should consider both the short- and long-term implications of their decisions, including potential impacts to roads, land, and the local community, as well as long-term economic considerations. As projects progress from the exploration phase to the development and production phases, the transportation plans can change, shifting from staging and storage of materials on well pads, to also include developing and using central staging and storage areas within the project area, which can improve transportation efficiency and reduce transportation risks. To the extent allowed by state and local regulations, consider and plan for use of road easement for gathering lines and other pipelines.

Prior to transporting any materials, operators and contractors should have spill prevention and contingency plans in place. This should include elements such as identifying local emergency contacts, identifying alternate travel routes, journey management, spill planning and notifications. Spill and contingency planning is discussed further in 6.4.1. State and local regulatory agencies may have spill prevention and control requirements that are in addition to the federal requirements. In addition, operators and contractors must comply with regulatory requirements associated with transportation of materials and equipment, such as the DOT's Hazardous Materials manifesting and placarding requirements.

11.1.2 Trucks and Transport Vehicles

Sand, additives, and equipment used during hydraulic fracturing are typically transported and delivered to the well pad by trucks. Water is generally delivered in tanker trucks that can arrive over a period of days or weeks. Water may also be delivered by pipelines or flowlines, which is discussed further in 11.1.4. Careful planning of transportation logistics is vital in order to maintain a safe and efficient operation.

11.1.3 Regional Transportation Plans

When hydraulic fracturing materials are transported by truck, operators and contractors should develop a regional transportation plan that includes the estimated amount of trucking required, hours of operations, appropriate off-road parking/staging areas, and routes. Considerations for the transportation plan include the following:

a) regulatory requirements;

b) reduce the need for additional traffic controls;

c) public input on route selection to maximize efficient driving and public safety;

d) landowner requirements;

e) peak traffic hours, school bus hours, community events, and overnight quiet periods;

f) notifying local emergency management agencies and highway departments of general transportation plans;

g) upgrades and improvements to public roads that will be used frequently;

h) advance public notice of any necessary detours or road/lane closures;

i) off-road parking and delivery areas at the site.

Detailed guidance for lease road planning, design and construction, maintenance and reclamation, and abandonment are also provided in API 51R.

11.1.4 Pipelines and/or Flowlines

One alternative to the transportation of fluids by truck is the use of temporary or permanent surface pipelines and/or flowlines to transport water to surface impoundments and well sites. The use of multi-well pads makes the use of central water storage easier, reduces truck traffic, and allows for easier and centralized management of produced water. In order to make transportation more efficient and reduce potential impacts, operators should consider constructing storage ponds and drilling water wells in cooperation with private property owners.

Design of the pipelines should include but not be limited to, the compatibility of the piping material with the fluids being transported and anticipated fluid flow rates and operating pressures. Design and operational safeguards should be in place to identify any piping or component failure so that operations can be stopped and corrective measures implemented.

11.2 Transportation Execution

11.2.1 Transportation Requirements

Materials and equipment must be transported to and from the site of hydraulic fracturing operations in accordance with federal, state, and local regulations. In addition, the transportation plan described in 11.1 should be reviewed as well.

11.2.2 Vehicle inspections

Operators and contractors should conduct vehicle inspections including, but not limited to, the following elements:

a) lighting systems;

b) tires and wheel condition;

c) windshield and wiper condition;

d) coupling devices;

e) service brakes;

f) vehicle fluid levels and condition;

g) belt and hose condition;

h) secured loads;

i) open-ended lines;

j) discharge valves.

11.2.3 Pipeline Requirements

When using pipelines to transport fluids, local, state, and federal requirements must be followed. Pipeline material should be compatible with the fluid being transported in order to reduce corrosion. Pipelines should be sited such that potential damage from accidental contact is reduced. In addition, operators should maintain and monitor pipelines to reduce the chance of spills. Pipeline maintenance is discussed further in 12.4.2.

11.3 Documentation and Data Collection

Records must be maintained for vehicles, regulated pipelines, and employees as required by DOT and other applicable regulations. In addition, operators and other contractors should document vehicle inspections, transportation plans, and emergency response procedures and notifications. See Section 6 for spill prevention and contingency recommendations.

12 Mobilization, Rig-up, Execution, and Demobilization

12.1 General

Hydraulic fracturing is a complex operation that should be performed by trained personnel who understand the operation of the fracture treatment, as well as their role and the role of the equipment they operate or the material they manage. Job management and control responsibilities should be defined and communicated to personnel on location. Key personnel operating the equipment involved in the hydraulic fracturing operation and others on-site during the fracture stimulation operation should work together following a work flow that can be safely and quickly modified in response to changing conditions.

Communication and training are important elements of a successful operation. A standard operating procedure (SOP) for fracturing operations should contain information about the equipment used, safe-operating practices for the equipment, start-up and shutdown procedures and emergency procedures. These SOPs can vary as a project moves from exploration to development and throughout the life-cycle of the reservoir. For example, once field activity levels move from exploration into development, the hydraulic fracturing equipment can be based in a field and can move only from pad to pad or well to well instead of returning to the service company’s base after each job.

12.2 Pre-job Hazard Assessment

A pre-job hazard assessment shall be conducted before each job to identify and assess hazards associated with a particular activity performed under a specific set of conditions, in this case hydraulic fracturing. A job safety analysis (JSA) is a commonly used hazard assessment tool.

Once the risks from the identified hazards have been assessed and determined to be significant, the controls to mitigate those hazards can be identified and implemented. Some examples of conditions that should be reviewed are:

— changing fracture fluid composition;

— changing location of the pumping equipment; and

— elevation changes in the terrain, etc.

Assessing changing conditions is a critical element in hazard identification.

A pre-job hazard assessment breaks down the job into steps or actions and assigns the possible outcomes from the action. These outcomes are typically driven by safety, but can also encompass environmental outcomes as well. Environmental outcomes such as releases of gases or liquids that can have potential environmental impacts if not properly mitigated can be identified and mitigation steps determined.

Safety measures such as fencing, rescue flotation devices, ropes of wires for egress should be considered. In addition, netting or other means for preventing wildlife from entering the impound must comply with applicable regulations.

12.3 Mobilization

Mobilization is the logistical effort of moving the equipment, materials and personnel to the well pad. Layout of the well pad determines how moving the equipment and materials will be accomplished. The amount and size of equipment should be reduced to limit the potential impact on public and lease roads (see 5.6 and 11.1 for additional details). If lease roads are watered to reduce dust or in a wetter climate, it may be necessary to clean public roads where truck traffic exits the lease road. Reducing the amount of materials necessary for the job can also decrease the truck traffic to the well site thus limiting the potential environmental impact of the well. The same applies to reducing the personnel and equipment required on the well site. Having multiple wells on a pad that are completed in sequence can also reduce the amount of traffic.

A journey management process should be used prior to moving equipment or personnel. Journey management is the plan for traveling from Point A to Point B in the safest way possible. The use of journey management can reduce the frequency of vehicle incidents and thus reduce potential environmental impacts. Journey management typically includes the following:

a) pre-journey vehicle inspection;

b) weather conditions;

c) pre-journey rest schedules for drivers;

d) route planning;

e) time and location of planned breaks for longer journeys;

f) scheduled arrival time and procedures for tracking and managing late arrivals;

g) incident response procedures;

h) convoy spacing.

12.4 Rig-up

12.4.1 General

Once the hydraulic fracturing design, equipment layout, and pre-job hazard assessment have been reviewed on location, the rig-up of the equipment necessary to do the hydraulic fracture job may commence. When equipment is maneuvered into tight spaces, care should be taken to not puncture fuel tanks or other equipment to prevent spills. Cranes can be required to lift certain equipment or piping pieces into place. Piping components should be laid out from the water source to the equipment and from the equipment to the wellhead. Control cables should also be laid to connect equipment to the control center.

Rig-up shall use appropriate equipment with current maintenance and inspection records. Job management and control should be agreed on and communicated to personnel on location. Operation of the wellhead should be restricted to designated personnel only. Pressure pumping equipment and connecting piping shall be tested for leaks and pressurized to operating pressure. Temporary piping from the additive containers to the blender shall also be leak tested. See Section 6 for additional information on spill prevention, control, and response.

12.4.2 Piping

Rigid or flexible piping may be used to transport water from wells, ponds or municipal water connections. Piping may also be used for the transmittal of produced water associated with hydraulic fracturing operations. Piping shall be tested for integrity after installation and inspected as appropriate to ensure they are not leaking. Any identified leaks in the piping shall be repaired before continuing operation. Temporary lines should be flushed with fresh water before being dismantled, with the flush water disposed of according to appropriate state and federal requirements. Operators should not allow any unauthorized fluid to be discharged during the removal of the piping.

High-pressure piping is used to convey fracturing fluid slurries to the wellhead. Some form of overpressure protection shall be implemented. High-pressure shutdown devices shall be used to maintain a pressure safety margin and prevent damage to system integrity. These devices may be electronic pump kick-outs, pressure relief valves, burst discs, etc. Overpressure protection systems should be properly designed for the job. Sleeve-type line couplings shall not be used when there is a chance of line movement. Additional steps to reduce the potential of a release from high-pressure piping may include the following.

— Removing dead-end or unused piping and temporary connections when they are no longer required.

— Bracing piping subject to vibration to reduce movement and avoid fatigue failures. Ancillary equipment (pipe braces, clamps, slings, and tie-downs) shall be designed to meet the anticipated loads.

— Verifying that the pressure rating for high-pressure piping and equipment is equal to or greater than the anticipated pressures, including an adequate safety factor during the planned job.

— Removing piping that has been exposed to pressure exceeding its rated limit, unless recertified.

12.4.3 Equipment

12.4.3.1 Equipment, including wellhead valves, assemblies, and tree savers should be checked to verify that they are designed for well fluid conditions, as well as pressures and abrasion created by the fracturing fluids and proppants during the fracture stimulation (see API 6A). Fracturing valves or other devices may be used during fracturing to protect the original wellhead. The presence of contaminants such as H_2S or CO_2 can require additional design and safety considerations. Specially designed valves and equipment can be required to protect the wellhead and pumping equipment to prevent failures and accidental releases to the environment during the hydraulic fracturing operation.

12.4.3.2 Proppant handlers are used to move large quantities of solid proppant to the blenders and mixers. Augers or conveyor belts are used to transport the proppant from a large storage container. Care should be taken to reduce release of solids during delivery or handling. See 10.3.3.2 for more information regarding mitigation for dust.

12.4.3.3 Blenders and mixers are used to mix the fracturing fluids, proppant and additives. Equipment should be configured to reduce the potential for spillage of proppant or leaks of fracture fluids or additives. Since pumping equipment can experience leaks from the drive train (engine and transmission), pumps, tanks or piping connections, the pumping equipment shall be tested for leaks after it is connected. Hoses and connections shall be tested prior to the start of pumping operations.

12.4.3.4 Hammer unions, in addition to threaded and flanged connections, are used to connect the high-pressure piping to the wellhead. The entire piping system, including associated unions and other connections, shall be inspected and pressure tested to verify integrity and confirm the piping, unions and connections are free from defects, prior to use. The piping certification bands should indicate that the piping has recently been inspected and certified for use as well as thread and union compatibility. Piping without current certification bands should be replaced prior to pressure testing.

12.4.3.5 Blowdown lines should have properly sized control valves, fixed chokes, and be secured and inspected prior to use to prevent unintended movement.

12.4.3.6 Equipment, including pump packing and hydraulic lines, should be inspected prior to and during operation for leaks that can result in pumped fluids being spilled on the ground. Spills should be handled in accordance with the spill plan discussed in 6.4.1. Engines should be checked for leaking lube oil, coolant and other fluids.

12.4.3.7 Equipment should be painted and/or kept clean to provide protection from external corrosion.

12.4.3.8 Waste receptacles should be provided at appropriate locations for segregating and collecting discarded paper, rags, etc. and emptied on a regular basis.

12.5 Management of Change

A process should be developed and communicated to manage variations in operational risk. These risks, can be either intentionally or unintentionally created by the introduction of variations in process and equipment, and are not addressed by existing documentation. These risks should be managed by updating the pre-job hazard assessment.

When a change has been identified, well site management should employ a process consistent with the operator policies and procedures that may include the following:

— review of the operation and execution vs. design;

— preparation of a revised hazard assessment, if needed, including new risk mitigation;

— exemption(s) approved from proper level of management for both operators and contractors;

— communication to parties involved at the well site.

12.6 Execution

12.6.1 During the execution of a hydraulic fracturing treatment, several contractors may be entering and leaving the well pad during various phases of the operation. In the interest of safety and security, an appropriate method of tracking personnel at the well site at any given time should be implemented.

12.6.2 The operator and the service provider should monitor key treatment parameters (such as pumping rates, slurry density, and treating pressures) and compare these to expected values from the hydraulic fracturing design. Any significant deviations observed may be related to uncertainty in reservoir geology or in equipment performance that should be investigated. Well site personnel should have the responsibility and authority to cease work until a review of the activity can be concluded and it has been found safe to resume such activity.

12.6.3 Monitoring, corrosion abatement, or corrosion-resistant equipment should be considered if injected fluids are suspected of being corrosive or abrasive (including proppant). Operating procedures should provide for early identification of potential corrosion problems in failure-prone equipment. Operators should consider performing analyses of failures or malfunctions so that corrective action can be taken to reduce the potential for environmental incidents.

12.6.4 On well pads where several wells can be completed simultaneously, or in relatively quick succession, it is important that proper communication occurs among the contractors at each well site so that each knows what the other is doing, with coordination by the operator. This will enhance surface safety as well as subsurface efficiency of well completion and reduce the potential for any environmental incidents.

12.6.5 For longer hydraulic fracturing jobs, an appropriate plan should be developed to refuel equipment. Operators should consider the inherent environmental and safety risks to refueling equipment in high-pressure, high-temperature zones. Risks should be properly mitigated if refueling occurs during the hydraulic fracturing treatment. If the risks cannot be properly mitigated, then refueling should occur during downtime between jobs or stages.

12.7 Rig-down and Demobilization

Following the hydraulic fracturing treatment, the wellhead shall be properly isolated and connections to the wellhead shall be removed in accordance with the project design. Prior to subsequent operations, the pressure should be properly relieved in the high-pressure treating line through a secured bleed line to an approved disposal area. Operation of the wellhead should be restricted to designated personnel only.

The surface lines should be flushed with an appropriate fluid prior to any disconnection of lines or hoses. An appropriate fluid should be selected in colder climates to inhibit freezing. Catch pans at connections and drains on low points may be used to reduce spills and capture fluids. When disconnecting hoses and high-pressure treating lines, excess fluids should be removed. Such techniques include utilizing secondary containment systems, location liners or other temporary site protection systems. The hoses between the additive storage container and the pumps should be flushed as per manufacturer’s recommendations to reduce discharge. This typically entails properly disposing of the contents of the hose and flushing the line with an inert fluid.

When leaving the location, proper journey management techniques should be employed in accordance with 12.3.

12.8 Well Site Restoration

After rig down and demobilization, any unused fluids and additives should be removed from the well pad and either properly stored for future use or transported and disposed. If any spills have occurred on synthetic liners and/or surface soils on the well site, these materials should be excavated, removed, and properly disposed. Clean fill materials should be placed in excavated areas.

Operators should re-evaluate the condition of the well site, stormwater control and spill containment features, storage tank and impoundment areas and access roads. Repairs should be performed prior to installation/reinstallation of natural gas and/or oil production and processing equipment. If repairs are needed at the well pad, the surface of the well pad should be re-graded and re-compacted. Interim reclamation can proceed after the wells are put into production.

13 Storage and Management of Fluids and Materials for Hydraulic Fracturing Treatment

13.1 General

13.1.1 Fluids and Materials

Fluids and materials used on-site should be properly managed and stored to reduce the risk of spills and releases (see Section 6). Fluids and additives used at the well site are often stored on-site for varying periods of time. Fluids and additives used for hydraulic fracturing will generally be stored onsite in mobile tanks, containers, or lined surface impoundments. Alternatively, fluids and additives used on-site may also be stored and managed in central staging and storage areas in the project area prior to delivery on-site.

13.1.2 Safety Data Sheet

The safety data sheet (SDS) for each additive shall be obtained from the supplier or manufacturer, be reviewed prior to using the additive, and be readily available at the job site. The SDS contains information about proper storage, hazards to the environment, spill clean-up procedures, personal protective equipment required, and other information to reduce potential environmental impacts.

13.1.3 Personal Protective Equipment

Where there is a risk of chemical exposure due to handling of materials by field personnel, appropriate personal protective equipment (PPE) should be worn. Employees shall have training in the proper and appropriate use of the PPE required to perform their job duties.

13.2 Additive Management, Storage, and Use

13.2.1 General

Fracturing operations require the blending of relevant additives and mix-water at the well site. The types of additives used for these operations are described in Section 10. Due to the diversity of these additives' identities and individual risks, certain considerations shall be made to safely transport, track, handle, and store these additives at the well site. Several notes regarding care in the handling of these additives are included in the following.

a) Certain additives and fluid components have incompatibilities highlighted in their SDS. Whether at a well site or in a warehouse, known incompatible materials should be stored separate from each other with barriers that prevent their mixing in the event of a potential spill. See 13.1.2 for more information on hazards and SDS considerations.

b) The hazards of mixtures or dilutions should be considered during pre-job planning.

c) Avoid releases of additives and blended fracturing fluids to the environment through the proper selection of equipment, pressure testing of piping, and the use of secondary containment.

d) The potential for spills can exist at junctions that convey additives or blended fluid. Well site personnel should provide containment at unions and junctions of hoses and/or low-pressure piping to other hoses/irons or equipment. For more detailed information on secondary containment considerations, see Section 6.

e) Using cranes and forklifts to move or convey large volumes (including "big bags" and totes) of additives between equipment at the well site requires special consideration to avoid a spill or personal injury from dropped items.

f) Dust and particulates mobilized during delivery and addition of solid materials can also provide some airborne risks to well site personnel. Advance planning should include a means to mitigate airborne particulates and dust during solid material addition. See 10.3.3.2 for detailed information on silica dust considerations.

g) Certain additives in pure form have special handling considerations and can require dedicated containers for storage and transportation of these materials. Examples include oxidative breakers, solvents with low flash-point, and others. See 6.2 for more information related to considerations in material transportation.

13.2.2 Additive Storage

Additives brought to a well site for either hydraulic fracturing or production operations are typically brought on-site in and stored in portable tanks. Additives shall be stored in their original packaging with proper identification or labeling. During storage, additive suppliers and operators should store materials that are compatible with the tank or container. Additives should be stored in impermeable secondary containment. Due to risks in the event of a release at the location, incompatible additives should be stored separately.

13.2.3 Additive Management

Operators and contractors have the responsibility to properly manage and use appropriate handling procedures for materials (including base fluids and additives) that can be used as a fracture fluid component. Contractors work with operators for optimal fracturing designs, which should include a full complement of suggested fluid alternatives, along with the potential environmental impacts and costs associated with each fluid additive alternative. Training and procedures for operating and handling for each additive used in the fracturing process improve responsiveness to potential surface incidents. As part of the hydraulic fracturing treatment, contractors shall provide operating and handling procedures for each additive used, including those for emergencies and disposal.

Components of fracture fluids, including water, additives, and proppants, should be managed properly on-site before, during, and after the fracturing process. Ideally, fracture fluid components should be blended into the fluids used for fracturing only when needed (‘on the fly’) to reduce the risk of high volume fracturing fluid spills. Any unused products should be removed from the location by the contractor or operator as appropriate. The job planning process should evaluate the possibility of circumstances that can delay the fracture operations and provide a plan for proper material management. This includes management of fluids that remain in lines, tanks and other containment devices after the fracturing has been completed.

13.2.4 Material Balance

Material balance can be used to identify faulty flowmeters, faulty additive pumps, storage container leaks, or software malfunctions during the treatment. By comparing planned volumes to actual volumes pumped, anomalies can be identified and quickly corrected.

Prior to pumping the treatment, the contractor and operator should review additive requirements and compare these against actual volumes present on location verified by weigh tickets, physical tank measurements and container count. A material balance plan highlighting planned base fluid, proppant and additive addition rates and concentrations is required at a minimum per stage and suggested per pumping step. The material balance plan should include:

— base fluid type (liquid/gas) and volume,

— proppant type, concentration, and volume, and

— additive name, type (liquid/dry), concentration, rate, and volume.

Prior to beginning pumping, flowmeters and additive pump rates should be verified by pumping a known volume at a predetermined rate near the desired addition rate commonly known as a ‘bucket check’. After the treatment, planned volumes should be compared to actual volumes to verify that proper addition was achieved.

13.2.5 Quality Assurance/Quality Control (QA/QC)

Basic QA/QC tests performed on location can help to identify any issues with additive contamination or integrity loss that may have taken place during loading and transport of additives to location. These QA/QC techniques include two types of testing.

a) Functional QA/QC testing includes testing of the blended fluid (or proppant) to ensure that the blend has sufficient ability to execute the fracture according to design. These tests can include viscosity measurement (of linear/un-crosslinked gel), delay time measurement, or proppant sieve analysis.

b) Base-component analysis, which may include advanced testing of either mix-water samples or the individual additives that comprise the blended fluid. Several water analyses used in a fracturing execution look-back may include:

   — temperature;

   — pH;

   — specific gravity;

   — ion concentrations (chlorides, calcium, magnesium, sulfate, iron, carbonate, bicarbonate, hydroxides); and

   — bacteria presence.

Representative QA/QC samples should be taken and tested, both in pure form and in the blended fracturing fluid. Samples should be obtained for pure additives, mix-water, and base fluid to be representative of the bulk.

Hydraulic fracturing equipment, such as blenders and pumps, should be inspected prior to the job and monitored throughout the hydraulic fracturing treatment for proper operation, leaks, and loss of integrity. Piping should be pressure tested and monitored. Flow meters and additive pumps should be calibrated regularly. Site personnel should be trained in the correct procedures for transporting and handling hydraulic fracturing fluids and should have operational knowledge, including testing and inspection procedures, of the equipment used during the treatment. Spill management is discussed in more detail in Section 6.

13.3 Produced Water Management and Storage

13.3.1 Produced Water Management after Hydraulic Fracturing

After the hydraulic fracturing treatment, the produced water from the well may be flowed back into storage tanks, surface impoundments, production equipment, or another suitable container to await proper disposition. The operator should also manage the excess mixed hydraulic fracturing fluids that remain in pumps and lines, and storage tanks after the hydraulic fracturing operation is completed, to include draining pumps and lines and either storing or disposing of excess mixed fluids. Fluids must be managed in accordance with applicable regulations. For secondary containment recommendations, see Section 6.

Personnel involved with produced water management and handling should be trained on the hazards and proper management of produced water. Operators should be aware of the general produced water characterization to be able to identify and mitigate the potential worker hazards. The appropriate PPE and fluid management practices shall be used to protect personnel from contact with the produced water. Protection of well site personnel and the public from hydrogen sulfide exposure (if present) shall be performed in accordance with API 68.

13.3.2 Produced Water Management during Production Operations

Produced water in production operations is often managed in permanently installed facilities and flowlines and/or pipelines. After the produced water is separated from the produced oil and/or natural gas, it is typically stored in steel tanks or surface impoundments until the final disposition of the produced water has been determined (see 14.2). Regulations should be reviewed in order to determine appropriate secondary containment required for the storage of produced water on a well site. For additional spill prevention measures, see Section 6.

Personnel involved with produced water management and handling shall be trained on the hazards and proper management of produced water. Operators should be aware of the general fluid characterization to be able to identify and mitigate the potential worker hazards. The appropriate PPE and produced water management practices shall be used to protect personnel from contact with the produced water.

13.3.3 Produced Water Storage in Surface Impoundments

Surface impoundments, including those used for temporarily storing produced water from hydraulic fracturing, shall be designed, sited, and constructed in accordance with existing local, state and federal regulations. In some cases, an impoundment requires prior authorization from one or more regulatory agencies and/or landowner, or can require a separate permit specifically for the impoundment's functional use. Natural or synthetic liner systems should be considered for surface impoundments storing produced water (see 5.3). The operator should evaluate site-specific hydrologic conditions and produced water characteristics to guide liner selection. Storage impoundments containing produced water associated with hydraulic fracturing operations may need larger capacities than storage impoundments used in conventional operations.

Operators may consider the use of centralized impoundments to manage produced water to enhance efficiency and limit the number of impoundments. These impoundments should be designed and constructed to provide structural integrity for the life of their operation. Proper design and installation should reduce the risk of a failure or unintended discharge. Additional information can be required by regulatory authorities for centralized surface impoundments for produced water. For such facilities, this information can include an initial review of site topography, geology, and hydrogeology, in addition to inspection and maintenance procedures—especially if such impoundments are within defined distances from a water reservoir, perennial or intermittent stream, wetland, storm drain, lake or pond, or a public or private water well or domestic supply spring.

Operators should consider soil conditions, and impoundment design and construction, to prevent infiltration of produced water into the subsurface. There may be a state requirement for a natural or artificial liner designed to prevent the downward movement of produced water. Typically, liners are constructed of compacted clay or synthetic materials like polyethylene or treated fabric that can be joined using special equipment. Impoundments used for long-term storage of produced water must be sited in accordance with state and local regulations governing stream setback distances to reduce the risks from unauthorized discharge to surface waters. The operator should develop and implement monitoring procedures to assess the integrity of the liner system. The operator should also develop and follow an inspection and maintenance plan. Documentation should be kept on produced water volumes placed in and removed from surface impoundments. Surface impoundments must be properly closed in accordance with regulations. Produced water removed from surface impoundments should be reused or properly disposed. Refer to API E5, for additional guidance on impoundments and practices on minimizing waste generation in the upstream sector.

13.3.4 Produced Water Storage in Tanks

Many operators store produced water in tanks, which can be used in addition to or instead of surface impoundments. These tanks shall meet appropriate industry standards at a minimum, which may be specific to the use of the tank (e.g. use for temporary or more permanent tank batteries). Operators should consider soil conditions when placing the tanks within secondary containment. When designing produced water handling facilities, operators must comply with appropriate regulations (e.g. secondary containment, overflow prevention, air emissions controls) and review the spill prevention provisions in Section 6. If multiple tanks are used in series, the interconnections and valves should be checked daily to identify potential leaks.

13.4 Training

Both the operator and any on-site contractors should verify that personnel involved in hydraulic fracturing and production operations are trained in the proper procedures for transporting and handling site-specific hydraulic fracturing fluids, produced water, and additives. They should also have operational knowledge of the equipment to be used and of the procedures implemented to prevent leaks and spills during a hydraulic fracturing and production operations. The training should include, but is not limited to the following:

a) procedures for transporting and handling fluids, additives, and materials;

b) the equipment to be used and the procedures implemented to prevent leaks and spills during operations;

c) proper management, cleanup and disposal practices that should be used if any additives are accidentally spilled or leaked;

d) proper management and disposal practices that should be followed during flowback operations including gas, liquid, and solid components;

e) procedures for testing and inspecting equipment, hoses, and connections prior to, and during, pressure operations;

f) procedures for collecting fluids remaining in lines including the use of collection buckets, catch basins, or vacuum trucks; and

g) emergency remedial actions in the event of a spill or release to avoid and reduce potential impacts to soil, groundwater, and surface waters.

13.5 Documentation

Operators should document and maintain information about hydraulic fracturing fluid, produced water and additive management and storage at the well site. Operators may be required to provide information to regulatory agencies. Such information may include:

a) site design and capacity of storage impoundments and/or storage tanks;

b) the number of impoundments and/or storage tanks on the well pad, as well as their individual and total capacity;

c) documentation of secondary containment at the site;

d) SDS for additives used and stored at the site;

e) additives and ingredients used and stored at the site as provided to a state reporting website or FracFocus.org;

f) description of planned public access restrictions, including physical barriers and distance to edge of the well pad;

g) description of how liners are to be installed to prevent possible leakage from impoundments, in locations where liners are required by state or local regulations;

h) volume(s) and source(s) of produced water and its basic characterization;

i) spill reports.

14 Management of Solid and Liquid Wastes from Exploration, Development, and Production Operations

14.1 Waste Management Planning

There are a variety of wastes generated during exploration, development, and production operations. Handling and management practices for these materials are well established and covered under state and sometimes federal oil and gas and/or environmental regulations. As projects progress from the exploration phase to the development and production phases, the nature and volume of solid and fluid wastes are likely to change. Therefore the operator's waste management decisions should be reviewed periodically. Operators should be prepared to adapt to changing waste treatment technologies/efficiencies and regulatory requirements.

Management of waste from stimulation and completion operations should take a life-cycle approach to identify the best overall solution. Waste management should be based on the standard hierarchy, as discussed in 14.2. Regulations often provide some flexibility that can allow an operator to select the best overall management approach for their specific situations. Waste management processes should remain open to innovation, process changes, and improvements that are balanced with practices and procedures influenced by what is technically sound, protective of the environment, and operationally efficient.

The operator should develop a waste management plan. Waste management planning should start at the point of material selection and go through the final management of the material after its use, including the management of treatment residuals.

API E5 provides recommendations regarding the organization and content of a waste management plan. The content and complexity of a specific plan will depend on several factors including an operator's activity level, the complexity of the operations, and the applicable regulatory requirements.

The waste management plan should contain information on waste generation and management procedures including, but not limited to the following:

a) source reduction;

b) reuse;

c) storage and containment;

d) incident response and reporting;

e) characterization;

f) transportation and custody tracking;

g) disposal.

The area of coverage and complexity of the Waste Management Plan should be determined by the operator's needs and can range from a single well site to multiple states.

Operators should perform a review of a waste management facility that is being considered for waste treatment or disposal. Reviews can include but are not limited to: permits to operate, compliance history and continued compliance performance, current operating practices, financial stability, and ultimate disposition of the waste.

The operator should be aware that many states have specific regulations applicable to the management of reused materials and associated treatment residuals. The operator should pay particular attention to the management of treatment residuals since these materials are typically disposed of off-site.

14.2 Waste Management Hierarchy

14.2.1 General

Exploration and production operations, including hydraulic fracturing treatments, generate relatively few waste streams. See API E5, which covers waste management practices in general. Wastes generated during the well completion and stimulation process are primarily fluids brought to the surface as a new or reworked well is brought on for production. Regardless of the operational source of the waste, the three tier waste management hierarchy provides sound guidance for responsible management of those materials.

Waste management should be based on the standard hierarchy as follows:

— source reduction,

— reuse,

— disposal.

The objective is to reduce the volume of waste at the source and ultimately the amount of waste being disposed.

14.2.2 Source Reduction

14.2.2.1 Volume Reduction and Alternative Base Fluids

Using alternative base fluids can result in reduced water use with a corresponding reduction in waste generated. Some examples of alternative base fluids or gases include nitrogen, carbon dioxide, liquefied natural gas or natural gas liquids, where these alternatives can meet the operational objectives. See Section 9 and Section 10 for factors that can affect alternative base fluid considerations. If alternative base fluids are used, appropriate environmental and safety aspects should be addressed.

14.2.2.2 Additive Elimination or Reduction

Operators should periodically review the need and effectiveness of each additive (or the ingredients that make up that additive). Vendor and supplier recommendations for additives and/or formulation of those additives should be reviewed so that the additive volumes and the materials selected reduce the potential environmental effects while providing the required level of well performance and treatment execution. Operators should use the minimum application rates necessary and substitute additives or ingredients that reduce potential environmental impacts, whenever practical.

14.2.2.3 Additive Substitution

As noted above, operators and contractors should periodically review their treatment recommendations and formulations to reduce any potential environmental effect of additives while meeting the specified performance objectives of the operation. Additives that reduce potential environmental effects are discussed in Section 10.

14.2.2.4 Inventory Control and Management

The operator and contractors should control and manage the recommended amounts of additives so only the necessary quantities are used to meet the operational performance objectives. Materials or other supplies that are not completely used on a job and are unlikely to be used on subsequent jobs can be returned to the supplier or contractor if possible. Excess materials may be required to be managed as waste. Unused portions of additives should not be transferred to new containers, unless original packaging is unusable. Unused or partially used containers of material shall be appropriately labeled. See Section 13 for more information on storage of materials on-site.

14.2.2.5 Process Modification

The operator should periodically gather data necessary to conduct performance assessments and sensitivity analyses that will allow evaluation of well performance versus well stimulation practices. The intent of this activity is to optimize well performance by evaluating various aspects of stimulation and completion operations that can lead to lower potential environmental effects including additive/product substitution or minimization, optimization of treatment practices, and reduction of waste volumes.

14.2.2.6 Housekeeping

Stimulation and completion activities are complex operations and good housekeeping at the work sites supports a safe and environmentally sound operation and reduces the generation of additional waste. See 6.4.4 for more information on housekeeping practices.

14.2.3 Reuse

14.2.3.1 Planning

The reuse of solid and liquid materials recovered from a well requires careful evaluation and planning. The operator should have a thorough understanding of the operational, regulatory, and environmental implications of using recovered materials in subsequent jobs. This is an area of continually improving technology and operators are encouraged to consider reuse whenever practical. Some of the factors that should be considered include:

a) any regulatory requirements associated with the reuse options;

b) the physical and chemical properties of the material to be reused;

c) any treatment the material needs before reuse;

d) the operational and life-cycle considerations of reuse when balanced against approved disposal options;

e) safe and environmentally sound storage and transportation of the material until reuse;

f) the local or regional impacts of reuse compared to existing waste management practices.

14.2.3.2 Treatment Technology Evaluation

The operator should evaluate the nature and character of the material(s) for potential reuse to determine if treatment of the material(s) is necessary. Based on this evaluation, treatment may not be needed. Multiple treatment technologies are available, and the suite of options is constantly evolving. Before starting the technology evaluation and selection process, the operator should know the treatment objectives for and the composition of their particular material(s). Frequently, this process involves laboratory testing of recovered samples, pilot testing of technologies, and trial and error.

Produced water rarely requires treatment to fresh water quality for reuse. Using lower quality water in hydraulic fracturing can require increased additives to achieve effective performance. See 9.2.3 for more information on using alternative water sources.

Treating materials for reuse can produce secondary waste stream(s). Sometimes these residual materials can be reused for another purpose, but more commonly they should be disposed of in an environmentally sound and regulatory compliant manner. Proper management of treatment residuals is an important step in the treatment/reuse decision making process. Operators should characterize these treatment residuals for their safe and environmentally sound reuse or disposal.

14.2.4 Disposal

When disposal is determined to be the best waste management option, operators must dispose of any waste material in accordance with the appropriate regulations. API E5 provides guidance for operators in selecting disposal sites, including review procedures to determine the suitability and management of a site.

NOTE Certain waste materials from exploration and production (E&P) operations are exempt from federal regulation as hazardous waste under the Resource Conservation and Recovery Act (RCRA); however, those waste materials are subject to state regulations. For surface discharge, refer to National Pollutant Discharge Elimination System (NPDES) requirements. It is necessary to gain authorization before discharging to publicly owned treatment works (POTW). Other regulations can apply.

Fluid industrial waste materials may be disposed through deep, subsurface injection wells in accordance with the Safe Drinking Water Act (SDWA), Underground Injection Control (UIC) program. Either the EPA or state agency with UIC authority regulates the underground injection of waste water into disposal wells, typically Class II injection wells. The technical challenges associated with underground injection require rigorous technical and operational requirements be met. Operators of UIC wells should collect and analyze information on the hydrology and geology of the potential disposal site and provide the appropriate regulatory authority with well construction plans to show how fresh water zones will be protected. Assessment of injection feasibility may include consideration of the following:

a) properties of target injection zone, including permeability and fracture-initiation pressure;

b) properties of natural barriers that can bound the injection zone, including permeability and fracture initiation pressure;

c) formation pressure, permeability, and porosity of the injection zone;

d) perforation density and spacing;

e) consideration of injection well monitoring over the lifetime of the well;

Other requirements may apply depending on state regulations.

NOTE Secondary or tertiary recovery injection wells are outside the scope of this document.

15 Air Quality

15.1 General

Operators should work to reduce air emissions to the extent practicable, including efforts to maximize safety and energy efficiency. Additionally, operational efficiency improvements have been shown to reduce time at a well site, reducing the local air emissions. The overall objective for operators should be to achieve reductions in air emissions in a technically feasible, safe, and efficient manner.

EPA has promulgated air quality regulations that are applicable to certain hydraulically fractured wells to control or reduce completion-related emissions. There are also other EPA rules on greenhouse gas reporting, engine emissions, and other types of equipment and operations. Operators should determine which federal, state, and local agency rules apply to their operations and know which agencies have delegated authority for compliance and enforcement.

15.2 General Emission Controls

Effective planning and allocation of resources to reduce emissions should be part of an operator’s development plan as an alternative to flaring or venting produced gas; this gas can be recovered for sale or use, where feasible. Options may include the following:

a) use as a fuel source for field operations;

b) sale into the market;

c) gas injection for reservoir pressure maintenance;

d) gas injection in enhanced recovery using gas lift;

e) gas for instrumentation.

When these options are not feasible, operators should use flares to reduce the venting of uncombusted gas.

Potential particulate matter emissions (e.g. transport related and proppant handling) and measures to reduce potential impacts are discussed in 5.7, 10.3.3, and 13.2.

15.3 Data Collection and Documentation

Operators should review the applicable air quality regulations, retain the required records, and submit the required reports. Operators must collect data to calculate air emissions such as CO_2, methane, volatile organic compounds (VOCs), SO_2, CO, NO_x, and PM necessary to comply with existing regulations.

15.4 Reduced Emissions Technologies

Reduced emissions technologies target the reduction of methane and VOC emissions when a new well is brought on to production. One of the key elements of these technologies is to reduce emissions of hydrocarbon compounds during flowback to increase recovery of gas for sale or other beneficial uses. Reduced emissions technologies are separation systems designed to process early well production, which consists of a high volume of fluids. Reduced emissions technologies may not be feasible in all situations, such as when there is no available gas infrastructure or in low pressure production situations.

15.5 Engines

During stimulation and completion operations, operators should be aware of the operating condition and performance of the diesel engines that are frequently used. The use of natural gas as a supply fuel in place of diesel to power engines is increasing in field operations. Operators should consider fuel mixture applications with equipment contractors in areas where natural gas can be used. The modification of engine fuel systems should be conducted in accordance with manufacturer requirements.

The owner/operator of the pressure pumping equipment should maintain equipment and associated engines in accordance with manufacturer specifications.

Annex A
(informative)

Additives

A.1 General

Additive selection is heavily influenced by local geology, environmental footprint, source water chemistry, economics, and hydraulic fracture design goals. These factors should be considered concurrently to arrive at the appropriate selection.

Many constituents that make up additives used in hydraulic fracturing fluids are found in common household products.

Most industrial processes use chemicals and almost any chemical can be hazardous in large enough quantities or if not handled properly. Even chemicals that go into our food or drinking water can be hazardous. For example, drinking water treatment plants use large quantities of chlorine. When used and handled properly, it is safe for workers and near-by residents and provides clean, safe drinking water for the community. Although the risk is low, the potential exists for unplanned releases that can have serious effects on human health and the environment. By the same token, hydraulic fracturing uses a number of chemical additives that can be hazardous, but are safe when properly handled according to requirements and long-standing industry practices. In addition, many of these additives are common chemicals which people regularly encounter in everyday life [50].

Additive concentrations vary depending upon the factors above and additive chemistry. Typical ranges of concentrations can be found at state, federal or other public reporting sites such as FracFocus (www.fracfocus.org).

The design engineer should source additives as close to the usage points as possible to reduce the potential environmental impact from transportation of additives to and from the well site.

A.2 Polymer Gelling Agents

A polymer is a type of gelling agent used to create viscosity for the hydraulic fracturing fluid. Generally, higher polymer concentration yields higher fluid viscosity. Polymer type is generally selected based on temperature stability requirements. For example, guar gum is commonly used over a wide range of temperatures while hydroxypropylguar (HPG) and carboxymethylhydroxypropyl guar (CMHPG) provide lower residue but are used over a narrow temperature range. Other types of polymers being used in hydraulic fracturing fluids include cellulose based polymers such as hydroxyethlycellulose (HEC), xanthan biopolymer, and acrylamide copolymers.

Operators should work with contractors to perform laboratory testing with high-temperature, high-pressure rheometers to optimize the required amount of polymer based on expected temperature and pumping time. In addition, design engineers may consider utilizing low polymer techniques that can reduce water volumes, and polymer and additive concentrations.

A.3 Friction Reducer

In slickwater applications, a friction reducer is commonly added to the fluid to reduce the amount of drag forces and ultimately the friction forces of the fluid. A common friction reducer is polyacrylamide polymer, which is often emulsified in a liquid phase for addition; alternative versions of friction reducer are offered in dry form. In field practice, drag reduction up to 80 % or higher can be achieved.

A.4 Crosslinker

A number of ions and elements can be used to crosslink polymers to create highly viscous fluids. Borate, titanium, zirconium and aluminum compounds are known crosslinkers for fracturing fluids.

Borate crosslinkers are widely used as they exhibit recovery of viscosity after being subject to shear as seen in tubular or perforation during the treatment.

Titanate crosslinkers are widely used in low pH environments such as CO_2 based fracturing fluids but are considered shear sensitive.

When high thermal stability is required, zirconate crosslinkers are often used in combination with CMHPG polymers. Zirconate crosslinkers exhibit shear sensitivity as well.

Proper laboratory testing with fully formulated fracturing fluids can also optimize the required concentration required for the desired crosslinking time and thermal stability of the fluid.

A.5 Breakers

While polymer is used to create fluid viscosity, the residual polymer left in the fracture after the base fluid has leaked off can impair the retained conductivity of the proppant pack [51]. To reduce this negative impact, breakers are used to break the long polymer chains into smaller sized chains to improve fracture productivity.

There are many common chemistries used to break the long polymer chains including oxidizers, enzymes, and acids. Each has its application ranges and benefits, and concentrations should be optimized based on representative sample testing in the laboratory.

Proper laboratory testing with fully formulated fracturing fluids can also optimize the concentration required for the desired break profile for given temperature and pumping time.

A.6 Bactericides

Bactericides are added to polymer-based fluids to prevent viscosity loss due to bacterial degradation of the polymer and to prevent the introduction of bacteria into the producing reservoir. If sulfate reducing bacteria are introduced to a sulfate bearing reservoir, the sulfate can be reduced to hydrogen sulfide (H_2S) and sour the area.

Materials such as glutaraldehyde, chlorophenates, and quaternary amines can be used independently or in combination to control bacteria.

To reduce potential environmental risk of bactericides, operators can work with contractors to conduct proper laboratory testing to optimize the concentration required to control the bacteria levels present. In these tests, it is important to consider sources of bacteria that may be introduced into the fracturing fluid including water, additives and proppant.

Operators may consider alternative methods of controlling bacteria including chlorine dioxide, mixed oxidizers, hypochlorite, ultra-violet light, and ozone generation.

A.7 Surfactants

A surface acting agent, or surfactant, adsorbs on the interface between two immiscible surfaces. There are many applications of surfactants, but the primary use in hydraulic fracturing include lower surface tension of the fluid to enable easier and more complete flowback of the fluid.

Surfactants may also be used to ensure compatibility between in-situ reservoir fluids and any treatment fluids introduced to the reservoir. This typically requires compatibility tests with fully formulated treatment fluids and representative samples of reservoir fluid where concentrations of the surfactant can be optimized.

Surfactants can also be used to enhance the foaming properties of the fluid. Stable foams are required to maintain viscosity and proppant carrying capabilities of the fluid.

A.8 Clay Stabilizers

Clays are detrital mineral particles composed of silicon and aluminum oxide and are common constituents of reservoir formations. When exposed to fresh water, clays can react ionically and/or chemically to swell or disperse, both of which can lead to reduction in pore space in the matrix or hydraulic fracture.

To stabilize the clays and prevent this interaction, solutions containing 1 % to 3 % potassium chloride (KCL) are commonly used as a hydraulic fracturing fluid additive. There are chemical formulations which may assist in stabilizing clays and can be investigated with the contractor to determine suitability for specific applications. These include quaternary amines (such as choline chloride) and ammonium chloride. Choline chloride and sodium chloride may reduce potential environmental effects.

Bibliography

[1] API Specification 6A, *Specification for Wellhead and Christmas Tree Equipment*

[2] API Recommended Practice 12R1, *Recommended Practice for Setting, Maintenance, Inspection, Operation, and Repair of Tanks in Production Service*

[3] API Recommended Practice 51R, *Environmental Protection for Onshore Oil and Gas Production Operations and Leases*

[4] API Recommended Practice 52, *Land Drilling Practices for Protection of the Environment*

[5] API Bulletin 75L, *Guidance Document for the Development of a Safety and Environmental Management System for Onshore Oil and Natural Gas Production Operation and Associated Activities*

[6] API Recommended Practice 98, *Personal Protective Equipment Selection for Oil Spill Responders*

[7] API Recommended Practice 100-1, *Hydraulic Fracturing: Well Integrity and Fracture Containment*

[8] API Bulletin 100-3, *Community Engagement Guidelines*

[9] API Publication 7103, *Management And Disposal Alternatives For Naturally Occurring Radioactive Material (NORM) Wastes In Oil Production And Gas Plant Equipment*

[10] API Bulletin D16, *Suggested Procedure for Development of a Spill Prevention Control and Countermeasure Plan*

[11] API Bulletin E2, *Management Of Naturally Occurring Radioactive Materials (NORM) In Oil & Gas Production*

[12] API Bulletin E5, *Environmental Guidance Document: Waste Management in Exploration and Production Operations*

[13] ASTM D5730 [1], *Standard Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater*

[14] SPE 50777 [2], *A Comparison of Freshwater- and Seawater-Based Borate-Crosslinked Fracturing Fluids*

[15] EPA *Field Sampling Procedures for Groundwater* [3], U.S. Environmental Protection Agency.

[16] EPA AP-42, *Compilation of Air Pollutant Emission Factors*

[17] 29 *CFR* 1910.120 [4], *Hazardous waste operations and emergency response*

[18] 40 *CFR* 98, *Mandatory Greenhouse Gas Reporting*

[19] 40 *CFR* 112, *Oil Pollution Prevention*

[20] 40 *CFR* 136, *Guidelines Establishing Test Procedures for the Analysis of Pollutants*

1 ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.
2 The Society of Petroleum Engineers, 222 Palisades Creek Drive, Richardson, Texas 75080, www.spe.org.
3 U.S. Environmental Protection Agency, Ariel Rios Building, 1200 Pennsylvania Avenue, Washington, DC 20460, www.epa.gov.
4 The *Code of Federal Regulations* is available from the U.S. Government Printing Office, Washington, DC 20402, www.gpo.gov.

[21] 40 *CFR* 60, *Standards of Performance for New Stationary Sources*

[22] Farinas, Mauricio and Ernesto Fonseca, *Hydraulic Fracturing Simulation Case Study and Post Frac Analysis in the Haynesville Shale*; SPE 163847, 2013.

[23] Soliman, M. Y., Loyd East, and Jody Augustine, *Fracturing Design aimed at Enhancing Fracture Complexity*; SPE 130043, 2010.

[24] Arthur, J. Daniel; Brian Bohm, and Mark Layne, *Hydraulic Fracturing Considerations for Natural Gas Wells of the Marcellus Shale*; paper presented at the Ground Water Protection Council 2008 Annual Forum, Cincinnati, Ohio; September 21 to 24, 2008.

[25] Porges, Robert and Mathew Hammer, *The Compendium of Hydrogeology*, National Ground Water Association, 2001

[26] Kaufman, P., G.S. Penny, and J. Paktinat, *Critical Evaluations of Additives Used in Shale Slickwater Fracs*, SPE Paper No. 119900, presented at the 2008 SPE Shale Gas Production Conference, Irving, Texas, November 16 to 18, 2008.

[27] *Ground Water Protection Council, State Oil and Natural Gas Regulations Designed to Protect Water Resources*, report prepared for the Department of Energy (DOE), Office of Fossil Energy, Oil and Natural Gas Program and the National Energy Technology Laboratory (NETL), DOE Award No. DE-FC26-04NT15455), May 2009.

[28] IPAA Guidance Document [5], *Reasonable and Prudent Practices for Stabilization (RAPPS) of Oil and Gas Construction-sites*.

[29] *Recommended Standards and Practices*, Appalachian Shale Recommended Practices Group, April 2012.

[30] Bolin, David E., Deputy Director of the State Oil and Gas Board of Alabama, Testimony before the House Committee on Oversight and Government Reform, October 31, 2007.

[31] Stowers, Don, "Unconventional gas outlook to 2020," *Oil and Gas Financial Journal*, Published: Aug 1, 2009 and the Energy Information Administrations, *Annual Energy Outlook*, 2009.

[32] Powell, Al, Oscar Bustos, Bill Morris, and Walt Kordziel, "Fiber-Based Frac Fluid A Hit In Bakken," *American Oil and Gas Reporter*, December 2006.

[33] Chariag, Belgacem, Schlumberger, Inc.; "Maximize reservoir contact;" Hart Energy Publishing, LP, *Global Exploration & Production News*, January, 2007.

[34] Satterfield, J, M. Mantell, D. Kathol, F. Hiebert, K. Patterson, and R. Lee, Chesapeake Energy Corp., *Managing Water Resource Challenges in Select Natural Gas Shale Plays*, presentation at the GWPC Annual Meeting, September 2008.

[35] Schlumberger. Fracturing, accessed: September 2008.

[36] Palisch, T.T., M.C. Vincent, P.J. Handren, SPE, *Slickwater Fracturing—Food for Thought*, SPE Paper No. 115766 presented at the 2008 SPE Annual Technical Conference and Exhibition, Denver, Colorado, September 21 to 24, 2008.

[5] Independent Petroleum Association of America, 1201 15th Street NW, Suite 300, Washington, DC 20005, www.ipaa.org.

[37] Schein, Gary W. and Stephanie Weiss, "Simultaneous fracturing takes off," Hart's *E&P Magazine*, Mar 19, 2008.

[38] Conway, Mike, *Shale gas fracturing water sources: What does the rock want?*, presented at the SPE Water Management ATW, Cooperstown, New York, March 31 to April 1, 2009

[39] Congressional Research Service, *Unconventional Gas Shales: Development, Technology, and Policy Issues*, R40894, October 30, 2009, http://www.fas.org/sgp/crs/misc/R40894.pdf.

[40] Huang F., R. Gundewar, D. Steed, and B. Loughridge, *Feasibility of Using Produced Water for Crosslinked Gel-Based Hydraulic Fracturing*, SPE Paper No. 94320 presented at the SPE Production Operations Symposium, Oklahoma City, Oklahoma, April 16 to 19, 2005.

[41] Louisiana Department of Natural Resources, "Ground Water Use Advisory: Commissioner of Conservation Recommends Wise Water Use Planning in the Haynesville Shale," press release web posted on October 16, 2008.

[42] Harper, J., "The Marcellus Shale—An Old 'New' Gas Reservoir in Pennsylvania," *Pennsylvania Geology*, vol. 28, no 1, published by the Bureau of Topographic and Geologic Survey, Pennsylvania Department of Conservation and Natural Resources, Spring 2008.

[43] Marcellus Shale Wastewater Partnership, *Permitting Strategy for High Total Dissolved Solids (TDS) Wastewater Discharges*, April 11, 2009.

[44] J. Daniel Arthur, P.E. et al, All Consulting, *Hydraulic Fracturing Considerations for Natural Gas Wells of the Fayetteville Shale*.

[45] Pickett, Al, "New Solutions Emerging to Treat and Recycle Water Used in Hydraulic Fracs," *American Oil & Gas Reporter*, March 2009

[46] Burnett, David B., *Well Site Produced Water Management in Oil & Gas Production*, presented at the SPE Water Management ATW, Cooperstown, New York, March 31 to April 1, 2009

[47] Myers, Roger, *Where Does All the Salt Water Coming From and How Do We Dispose of it?*, presented at the SPE Water Management ATW, Cooperstown, New York, March 31 to April 1, 2009.

[48] Ewing, Jay, *Water Management in the Barnett Shale*, presented at the SPE Water Management ATW, Cooperstown, New York, March 31 to April 1, 2009

[49] *Surface Operating Standards and Guidelines for Oil and Gas Exploration and Development—The Gold Book*, U.S. Bureau of Land Management.

[50] *Modern Shale Gas Development in the United States: A Primer*; U.S. Department of Energy, Office of Fossil Energy and National Energy Technology Laboratory; April, 2009.

[51] SPE 146832, *Environmentally-Focused Crosslinked Gel System Results in High Retained Proppant-Pack Conductivity*, J. Holtsclaw, D. Loveless, R Saini, J. Fleming; Society of Petroleum Engineers, October 2011.

AMERICAN PETROLEUM INSTITUTE

1220 L Street, NW
Washington, DC 20005-4070
USA

202-682-8000

Additional copies are available online at www.api.org/pubs

Phone Orders: 1-800-854-7179 (Toll-free in the U.S. and Canada)
303-397-7956 (Local and International)
Fax Orders: 303-397-2740

Information about API publications, programs and services is available on the web at www.api.org.

Product No. G100201