

Strategies for Addressing Salt Impacts of Produced Water Releases to Plants, Soil, and Groundwater

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Cover photo:

A produced water-impacted plot (left) contrasts with an adjoining salt-flat remediation plot (right) where the thriving halophyte, marsh hay cordgrass (Spartina sp.), was planted as plugs about five years previously in the Smackover oilfield of south Arkansas.

Photo courtesy of David J. Carty, GreenBridge EarthWorks

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PURPOSE OF THIS GUIDE

The exploration and production (E&P) industry uses great care during the handling and disposal of the produced water that is generated as part of oil and gas production. However, unintentional releases can occur. Depending on the chemical composition of the produced water and the nature of the local environment, salts associated with such releases can impair soils, vegetation, and water resources.

This guide provides a collection of simple rules of thumb, decision charts, models, and summary information from more detailed guidance manuals to help you address the following assessment and response issues:

1) *Will a produced water release cause an unacceptable impact on soils, plants, and/or groundwater?*
2) *In the event of such an impact, what response actions are appropriate and effective?*



HOW TO USE THIS GUIDE

Determining when a response action will likely be needed to protect soil, plants, or groundwater.	• ***Protecting Soil/Plants:*** *See Rules of Thumb on Page 2 and more detailed decision charts on Pages 4 to 5.* • ***Protecting Groundwater:*** *See Rules of Thumb on Page 3 and Planning Model on Pages 9 to 14.*
Selecting and implementing an appropriate remedial measure for impacted soils or plants.	• ***Remedy Selection:*** *See decision charts on Pages 4 to 5.* • ***Remedy Implementation:*** *See simple guidelines for natural remediation, in-situ chemical amendments, and mechanical remediation on Pages 6, 7, and 8, respectively.*
Evaluating potential impacts on groundwater resources.	• ***Planning Model:*** *See simple procedures for assessing potential effects on groundwater quality on Pages 9 to 14.* • ***Beneficial Use Criteria:*** *See general criteria for evaluating the potential use of water resources on Page 15.*
Background information on produced water and its potential effects.	• ***Produced Water Production and Disposal in the U.S.:*** *Page 16* • ***Definition/ Measurement of Key Parameters:*** *Pages 17 and 21* • ***Potential Impacts on Plants:*** *Page 18* • ***Potential Impacts on Soil:*** *Page 19* • ***Key Factors for Assessing Groundwater Impacts:*** *Page 20* • ***Example Site Assessment:*** *Pages 22 and 23*

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SOIL/PLANT IMPACT RULES OF THUMB

Evaluating Impacts - SOIL

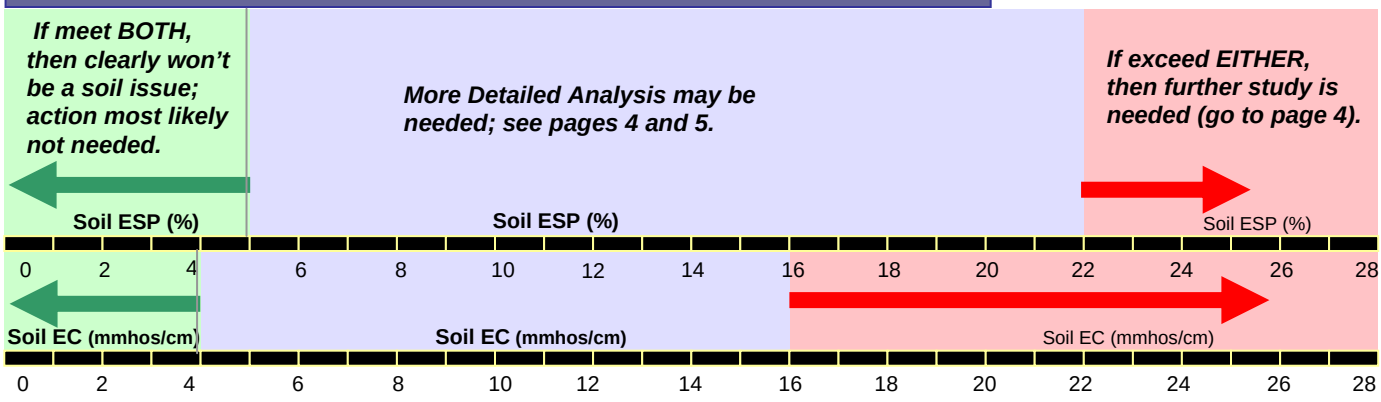
Information from API Publication 4663, *Remediation of Salt-Affected Soils at Oil and Gas Production Facilities* and other sources was compiled to develop the following "Rules of Thumb" for response to impacts by produced water. Each Rule of Thumb describes a set of conditions associated with a produced water release and the typical response to such conditions. These Rules of Thumb are for typical rangeland and farmland areas, but may not be applicable to environments with naturally high salinity. For further discussion of conditions not covered by these Rules of Thumb, please go to page 4.

TECH TIP:

See Page 17 for definitions of EC, CEC, TDS, ESP, and SAR .

IF THESE SOIL CONDITIONS RESULT FROM PRODUCED WATER RELEASE….	RULE OF THUMB IS:
CASE 1 Affected Soil EC > 16 mmhos/cm *OR* Affected Soil ESP > 22% (SAR > 20)	**FURTHER STUDY MAY BE NEEDED; GO TO PAGE 4** *Source: API Publication 4663*
CASE 2 Produced Water TDS < 3000 mg/L *AND* Affected Soil ESP < 12% (SAR < 10)	**A RELEASE WILL MOST LIKELY NOT HARM SOILS AND/OR PLANTS**
CASE 3 Produced Water TDS < 600 mg/L *AND* Affected Soil ESP < 12% (SAR < 10)	**CLEARLY WILL NOT BE A SOIL FERTILITY ISSUE** *Source: API Publication 4663*
CASE 4 Affected Soil EC < 4 mmhos/cm *AND* Affected Soil ESP < 5% (SAR < 5)	**CLEARLY WILL NOT BE A SOIL FERTILITY ISSUE** *Source: API Publication 4663*

Decision Chart for Soil Impact Rules of Thumb (based on Soil ESP and Soil EC)



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GROUNDWATER IMPACT RULES OF THUMB

Evaluating Impacts - GROUNDWATER

The following Rules of Thumb for response to groundwater impacts by produced water were developed as guidance using information from API Publication 4734, *Modeling Study of Produced Water Release Scenarios*. In that study, the authors performed several hundred computer simulations with the HYDRUS-1D model to determine the sensitivity of groundwater underlying a produced water release to various factors such as release volume, chloride concentration of the produced water, depth to groundwater, soil type, rainfall and hydrology of the area, and other factors. Each Rule of Thumb describes a set of site conditions associated with a produced water release and assesses the likelihood of an impact to groundwater. These Rules of Thumb may not be applicable to environments with naturally high salinity or areas with multiple releases over several years. For cases not covered by these Rules of Thumb, go to page 9.

CASE 1

Produced Water Release Volume > 100 bbls

AND

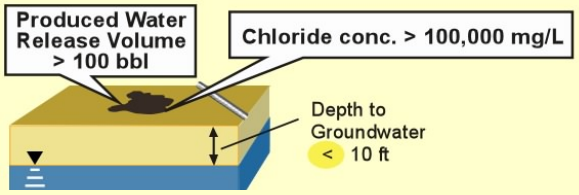
Produced Water With Chloride Greater Than ~100,000 mg/L

AND

Depth to Groundwater < 10 ft

AND

Unsaturated Soil Zone is Sandy



HAS POTENTIAL TO IMPACT GROUNDWATER QUALITY. FURTHER STUDY NEEDED - GO TO PAGE 9.

CASE 2

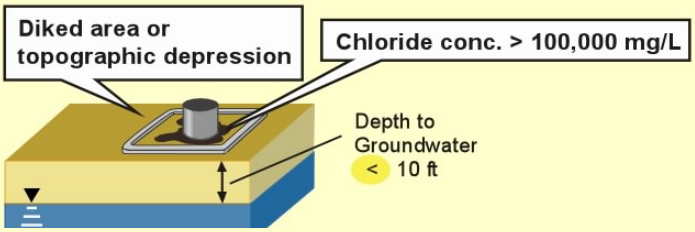
Entire Produced Water Release Collects in Bermed Area or Topographic Low, Causing Infiltration

OR

Produced Water With Chloride Greater Than ~100,000 mg/L

OR

Depth to Groundwater < 10 ft



THESE SITE FACTORS MAY INCREASE LIKELIHOOD OF IMPACTING GROUNDWATER - SEE PAGES 9 AND 20 FOR MORE INFORMATION.

CASE 3

Produced Water With Chloride Less Than ~100,000 mg/L)

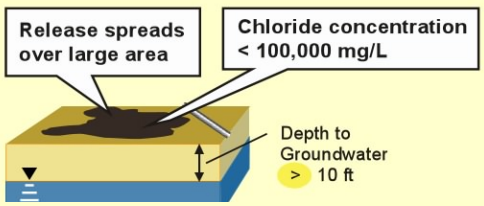
AND

Release Spreads over a Large Area

[e.g., Volume release (bbls) ÷ Area (sq. ft) < 0.015]

AND

Depth to Groundwater > 10 ft



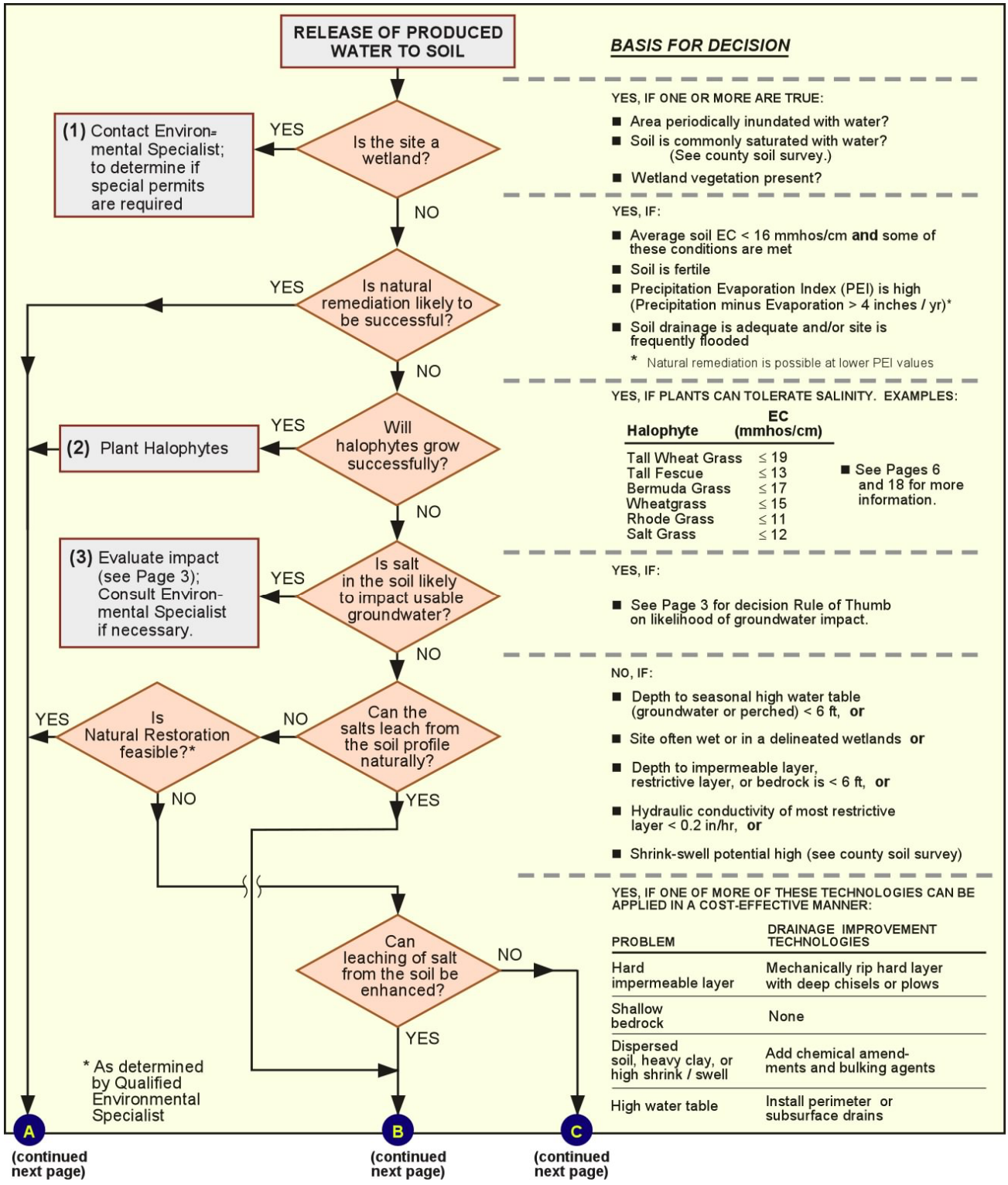
LESS LIKELY TO IMPACT GROUNDWATER.

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DECISION CHART FOR SOIL / PLANT IMPACTS

Evaluating Impacts - SOIL

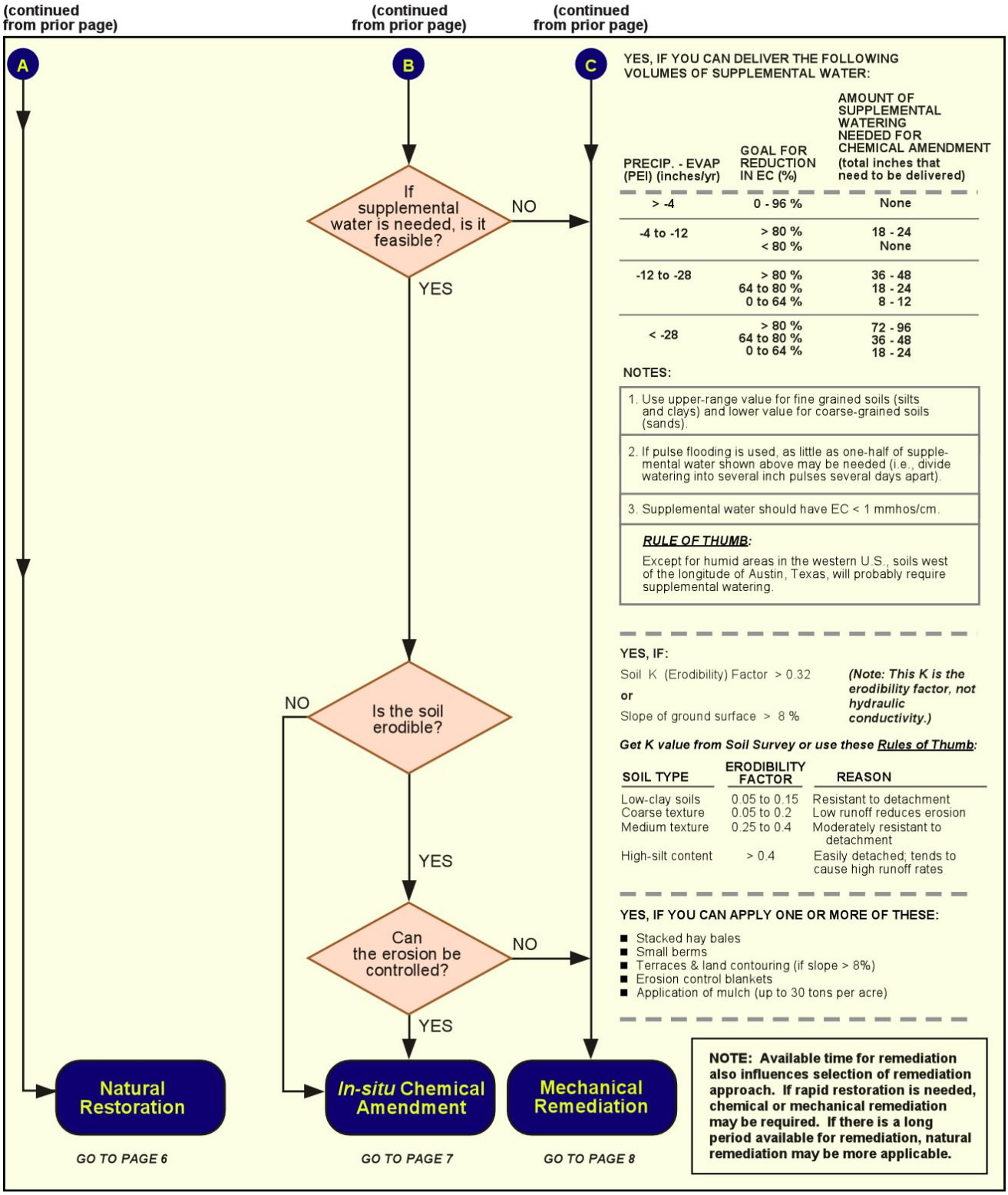
For those sites where produced water impacts to soils requires a corrective action, the following decision chart can be used to select appropriate remedial measures. More detail on specific technologies is provided on pages 7 – 8.



Decision Chart for Salt-Impacted Soils **(Adapted from API Publication 4663)**

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DECISION CHART FOR SOIL / PLANT IMPACTS (Continued)



YES, IF YOU CAN DELIVER THE FOLLOWING VOLUMES OF SUPPLEMENTAL WATER:

PRECIP. - EVAP (PEI) (inches/yr)	GOAL FOR REDUCTION IN EC (%)	AMOUNT OF SUPPLEMENTAL WATERING NEEDED FOR CHEMICAL AMENDMENT (total inches that need to be delivered)
> -4	0 - 96 %	None
-4 to -12	> 80 % < 80 %	18 - 24 None
-12 to -28	> 80 % 64 to 80 % 0 to 64 %	36 - 48 18 - 24 8 - 12
< -28	> 80 % 64 to 80 % 0 to 64 %	72 - 96 36 - 48 18 - 24

NOTES:

1. Use upper-range value for fine grained soils (silts and clays) and lower value for coarse-grained soils (sands).
2. If pulse flooding is used, as little as one-half of supplemental water shown above may be needed (i.e., divide watering into several inch pulses several days apart).
3. Supplemental water should have EC < 1 mmhos/cm.

RULE OF THUMB:

Except for humid areas in the western U.S., soils west of the longitude of Austin, Texas, will probably require supplemental watering.

YES, IF:

Soil K (Erodibility) Factor > 0.32

or

Slope of ground surface > 8 %

(Note: This K is the erodibility factor, not hydraulic conductivity.)

Get K value from Soil Survey or use these Rules of Thumb:

SOIL TYPE	ERODIBILITY FACTOR	REASON
Low-clay soils	0.05 to 0.15	Resistant to detachment
Coarse texture	0.05 to 0.2	Low runoff reduces erosion
Medium texture	0.25 to 0.4	Moderately resistant to detachment
High-silt content	> 0.4	Easily detached; tends to cause high runoff rates

YES, IF YOU CAN APPLY ONE OR MORE OF THESE:

- Stacked hay bales
- Small berms
- Terraces & land contouring (if slope > 8%)
- Erosion control blankets
- Application of mulch (up to 30 tons per acre)

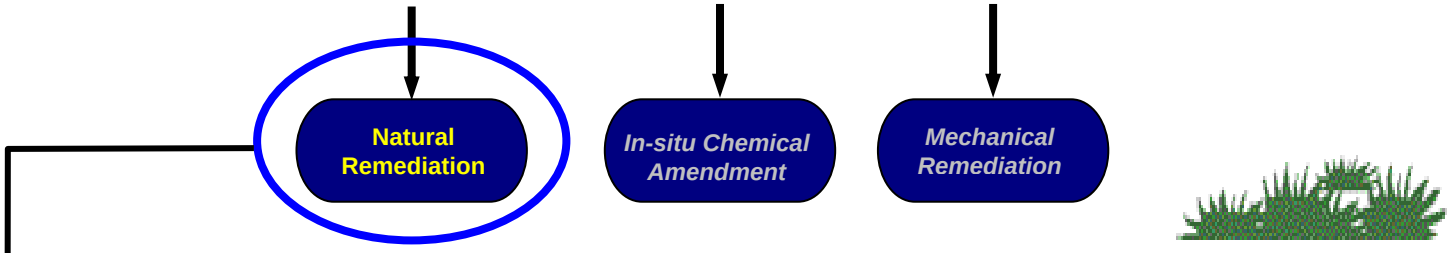
NOTE: Available time for remediation also influences selection of remediation approach. If rapid restoration is needed, chemical or mechanical remediation may be required. If there is a long period available for remediation, natural remediation may be more applicable.

Decision Chart for Salt-Impacted Soils - *Continued* **(Adapted from API Publication 4663)**

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NATURAL REMEDIATION OF SOIL IMPACTS

Responding to Impacts - SOIL



Soil Remediation Alternative 1: *Natural Remediation*

Concept: Use plants and natural water flushing to restore salt-impacted soils. This option is preferable in cases where remediation equipment can create additional soil damage (such as wetlands).

OPTION A.
Monitored Natural Revegetation

Approach: Allow natural revegetation to occur over 1-to 3-year time period and monitor the revegetation process. The affected area should be monitored for barren zones and stressed vegetation over time. If monitoring shows revegetation process is too slow, consider other methods. This method works best with sandy soils and soils containing limited clay. In some cases adding mulch, fertilizer, and water (see Option B, below) can speed up revegetation.

OPTION B.
Plant Salt-Tolerant Vegetation

Approach: Plant halophytic vegetation that is suitable for the climate and the soil conditions and that can tolerate elevated salinity (see table below for examples of halophytic grasses). Add mulch and fertilizer as necessary:

Mulch Rule of Thumb: *Till in 2 to 4 inches of mulch over affected area (less for coarse soils, more for fine-grained soils; about five 60-lb bales of hay for every 1000 sq. feet).*

Fertilizer Rule of Thumb: *Add about 28 pounds of 13-13-13 fertilizer for every 1000 sq. feet. (For more detail, see API Publication 4663) (Don't add too much fertilizer in a soil; fertilizers can act like salts.)*

Watering Rule of Thumb: ***GENERALLY DO NOT ADD WATER BY ITSELF IF SALT IMPACT HAS ALREADY ENTERED SOILS CONTAINING CLAY. IF YOU ARE GOING TO ADD WATER, FIRST ADD CHEMICAL AMENDMENTS (see next page).***

For more detailed information on mulch / fertilizer addition, see API Publication 4663.



Halophyte-assisted natural remediation
Photo Courtesy of David Carty

EXAMPLES OF GRASSES THAT MAY BE USED FOR REVEGETATION

GRASS	HABIT	ACCEPTABLE PRECIPITATION RATES		SOIL TYPE	U.S. PLANTING SEASON	SEEDING RATE	SEEDING DRILL DEPTH
		Min (in/yr)	Max (in/yr)	L-M-H		(lbs/ac PLS drilled)	(inches)
Alkali Sacaton	Bunch	8	18	L-M-H	Summer	1/5	1/4
Basin Wildrye	Bunch	9	Irrigation OK	L-M-H	Late Fall/Spring	5	1
Western Wheatgrass	Sod	10	20	M-H	Early Fall/Spring	8	1/2 - 1
Beardless Wildrye	Sod	20	Irrigation OK	M-H	Late Fall/Spring	8	3/4
Tall Wheatgrass	Bunch	5	20	L-M-H	Spring	8	1/2 - 2

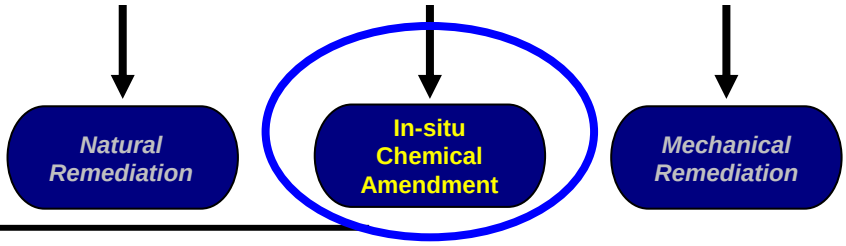
NOTES: This table only presents a few of the grasses that can be used for revegetation. A number of other grasses (such as Bermuda grass) are presented in API Publication 4663 and other literature.

SOIL TYPE: **L** = LIGHT - sands, loamy fine sands, sandy loams
M = MEDIUM - silty loams, loams, very fine sandy loams, sandy clay loams
H = HEAVY - clay loams, silty clays, clay

PLS = Pure Live Seeds.

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IN-SITU CHEMICAL AMENDMENT OF SOIL IMPACTS



Soil Remediation Alternative 2: *In-Situ Chemical Amendment*

Concept: Add a calcium-containing compound, such as gypsum, which serves to replace sodium (which changes the structure and porosity of clays in salt-impacted soils) with calcium and restores the structure of the soil. (See page 19.)

Add Gypsum or Other Amendment

Approach:

1) Improve drainage, if necessary.
2) Calculate how much gypsum to add using Calculation Method 1 or Method 2 (below) or use this *Rule of Thumb*:
   Add 13 pounds of gypsum per 100 sq. feet of impacted soil
3) Add chemical amendments to affected soil.
   - Solid Amendment: Incorporate from surface to depth of 1 to 2 ft using plow. Make sure amendment is in powdered or granular form.
   - Liquid Amendment: Apply over soil surface with or without mechanical incorporation.
4) Adding mulch and fertilizer may enhance rapid restoration (see page 6).
5) Use perimeter berms to contain rainfall or use sprinkler irrigation in affected area to increase infiltration and leach salts (sodium) from affected soils.

Rules of Thumb:

- *ADD CHEMICAL AMENDMENTS BEFORE IRRIGATION OR A PERIOD OF HEAVY RAIN.*
- *Pulse flooding (watering with a few inches of water every few days) can reduce water requirements by half.*
- *A final top dressing of gypsum or mulch can protect the soil surface from dispersing after a rainfall or water event.*
- *See **page 5** for amount of supplemental irrigation that is needed.*
- *Install erosion controls, if necessary.*



Addition of Chemical Amendment
Photo Courtesy of David Carty

TECH TIP 1:

If soil pH is between 5.5 and 8.5, and if chloride or nitrate will not impact groundwater, you can replace gypsum with:

- *Calcium Chloride* [$CaCl_2$:$2H_20$] at 0.85 pounds per pound gypsum requirement
- *Calcium Nitrate* [$Ca(NO_3)_2$] at 0.95 pounds per pound gypsum requirement

TECH TIP 2:

Adding more than the calculated amount of calcium will not hurt the soil.

Calculation Method 1: Amount of Gypsum Needed Based on Soil ESP and CEC

Formula:

No. of lbs of gypsum to add per square foot of impacted soil = [ESP - 5] x [CEC] x [0.00078]

(in pounds / ft²) *(in %)* *(in meq/100 grams)*

Calculation Steps:

1. Perform calculation for 0 to 1 ft layer.
2. Perform calculation again for 1 to 2 ft layer.
3. Add lbs per sq. ft. numbers together.
4. Multiply lbs of gypsum per sq. ft. by area of spill in sq. ft. to get lbs of gypsum.
5. If soil pH is <5.5, then may need to add $CaCO_3$ to replace some of the gypsum. See API Publication 4663.
6. If soil pH > 8.5, then may need to add sulfur or alternative chemical to decrease pH. See API Publication 4663.

Calculation Method 2: Amount of Gypsum Needed Based on Sodium Concentration in Produced Water Release

Formula:

No. of lbs of gypsum to add to affected area = [sodium concentration] x [6.94] x [volume spilled] x [0.00019]

(in pounds)

(sodium concentration in mg/L)
(volume spilled in bbl; 42 gallons per bbl)

Calculation Steps:

1. Calculate lbs of gypsum to add using formula shown above.
2. Note that sodium typically comprises 20-35% of the TDS concentration, and can be estimated as (0.2 to 0.35) x TDS (mg/L).

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