Rehabilitation Program in remediated soils of desert environment– Case Study

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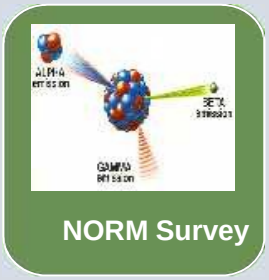
SEED (Sustainable Environmental & Economical Development) Project

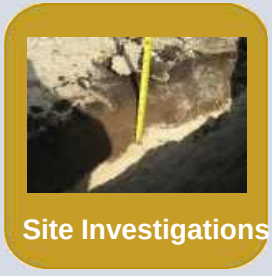
- Undertake an assessment of the land degradation caused by historical oil and gas exploration and production activities in KOC.

- Remediate & Rehabilitate the contaminated features exist with the company (Phase wise)


EOD/UXO



NORM Survey


Site Investigations


Oil Recovery

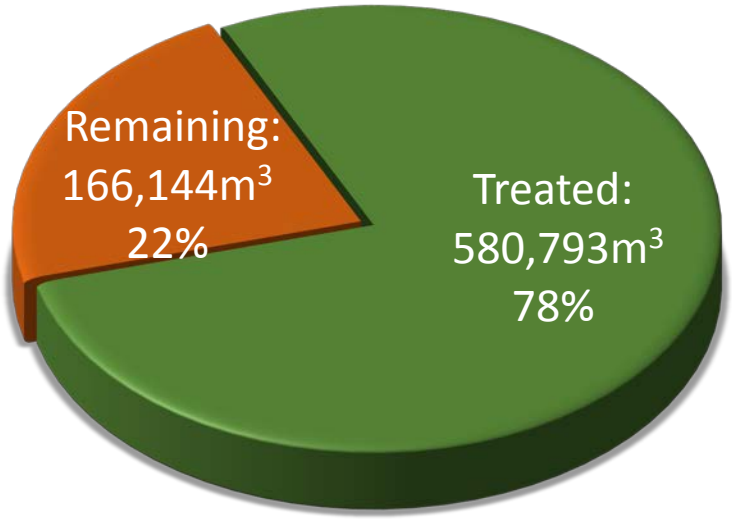

Remediation


Rehabilitation

Remediation of Oil Contaminated Soils

Soil Washing

Total Volume: 746,937m^3



Thermal Desorption

Bio-Remediation

ECOLOGICAL FUNCTION

Aim

- To ensure final soil system is capable of supporting native desert plant community, respective to the soil remedial approach applied.

Requirements

- The clean-up should ensure that soil remediated to either the Primary Ecotoxicity RS or Alternative Ecotoxicity RS is ecologically functional and able to support native flora. This may include for the application of soil amendments were deemed necessary; and

REMEDIATION SPECIFICATION

Primary Ecotoxic RS

- Soil within top 1.5m below finished grade;
  - Total PHC ≤ 5,580 mg/kg;
  - PAHs & BTEX compound specific;
  - Heavy Metals

Alternative Ecotoxic RS

- Soil within top 1.5m below finished grade;
  - Total PHC ≤ 10,000 mg/kg;
  - Salinity (≤ 4.5 dS/m, SAR 12); and

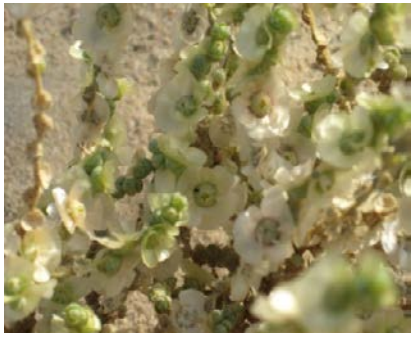
Commercial / Industrial RS

- Soil below 1.5m of finished grade;
  - Total PHC ≤ 30,000 mg/kg; and
  - PAHs compound specific.

ECOLOGICAL PERFORMANCE MONITORING

The establish vegetation blocks within selected features which the Company will monitor in order to:

- Confirm that ecological function has been achieved; and
- Demonstrate the ability of the selected remediation technologies and soil amendments to transform the contaminated areas back to a natural desert environment.



Ecological performance indicators comprise:

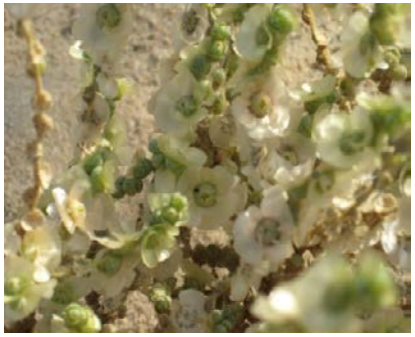
- Specified range of native Kuwait desert plants; and
- Experimental planted plots within designated effluent pits and sludge pits.

ECOLOGICAL PERFORMANCE MONITORING

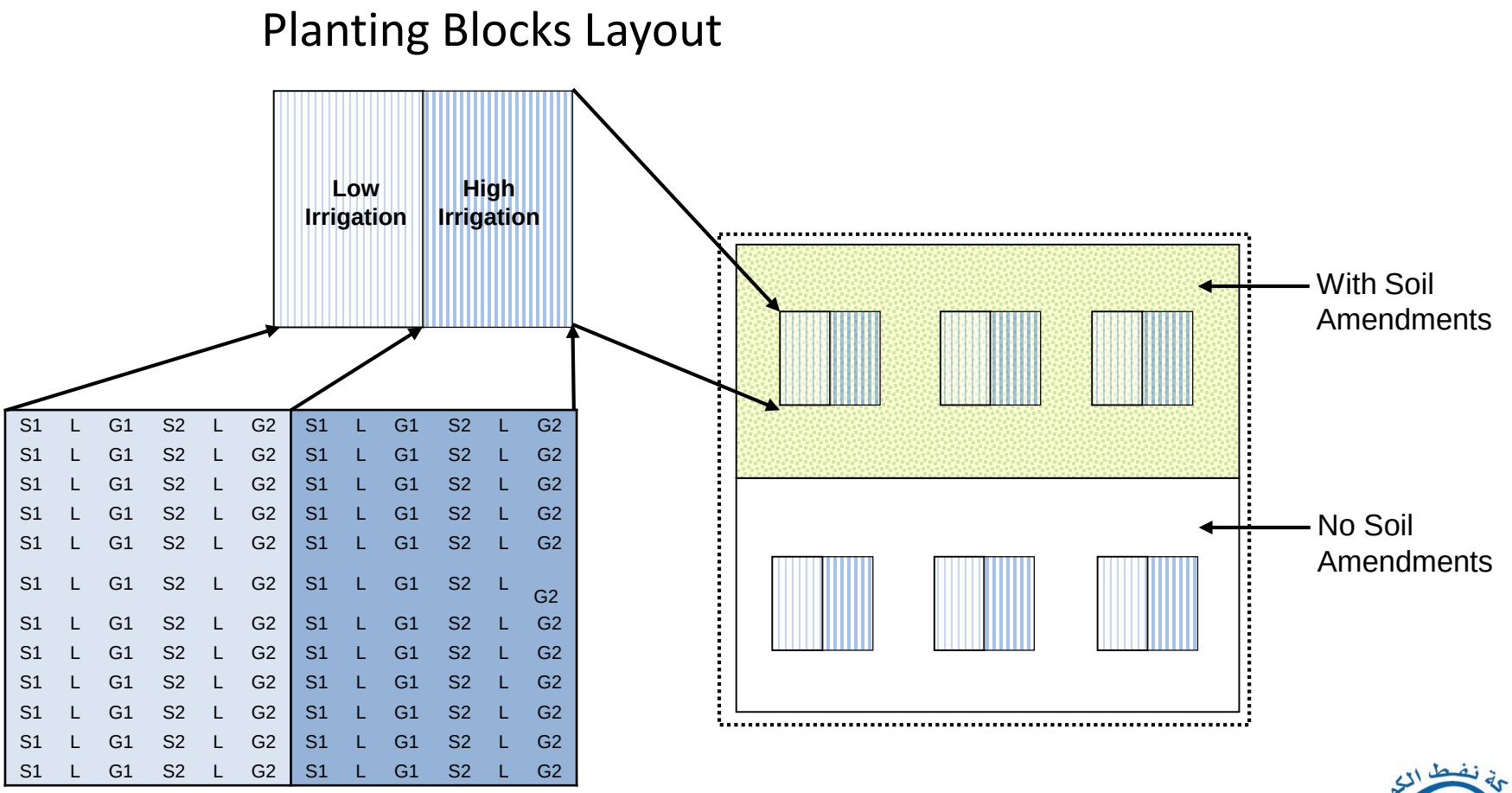
AFTERCARE, MAITENANCE & MONITORING

After Care and maintenance includes:

- Water delivery and Irrigation of installed vegetation fortnightly during the winter months (November to May inclusive);
- Fence and general site maintenance throughout the after care period;
- Monitoring - For each installed vegetation block :
  - Specified Soil Sampling and analysis twice a year;
  - Monitoring of plant health and survivorship; and



Planting Blocks Layout



S = Shrub G = Grass L = Legume

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Gatch Pit - Ecological Restoration

February 2014

July 2016

Ecological Experimental Design

- Experiment Period: November 2012 – April 2014
- 3 Control Areas in pristine soils: 432 plants,
- 3 Sludge and 6 Effluent Pits backfilled with remediated soils: 12,960 plants;
  - Comparison of plant survivorship & growth in pristine and remediated soils;
  - Comparison of initial different irrigation levels;
  - Evaluation of soil amendment requirements.

Acacia gerrardii (Talh)

Cyperus conglomeratus (Thanda)

Panicum turgidum (Taman)

Astragalus spinosus (Qatad)

Rhanterium epapposum (Arfaj)

Ziziphus spina-christi (Jujube)

Prosopis farcta (Yanbout)

Nitraria retusa (Gharqad)

Ecological Restoration – Planted species

- Planting of specified range of native Kuwait desert plants

  - Panicum turgidum (4,110 plants),
  - Cyperus conglomeratus (4,138 plants),
  - Rhanterium epapposum (4,102 plants),
  - Nitraria retusa (4,130 plants),
  - Prosopis farcta (6,228 plants),
  - Astragalus spinosus (468 plants),
  - Ziziphus spina-christi (1,548 plants),
  - Acacia gerrardii (72 trees),
  - Prosopis farcta (72 trees),
  - Ziziphus spina-christi (72 trees).

Sludge Pit - Ecological Restoration

August 2013

July 2017

Effluent Pit – Ecological Restoration

August 2010

July 2016

STATISTICAL APPROACH

Width Growth :

Width growth per species was measured immediately after planting and at the end of the monitoring period (18 months after planting).

Plants that died during the monitoring period were not included in the calculations of average plant width. Hence, the average is a weighted average calculated to account for the different number of survived plants used in averaging plant width in each planting block.

Survivorship :

Survivorship per species was determined at the end of the monitoring period (18 months after planting).

Averages have been calculated per species, per planting block, per irrigation type, per amendments application (yes/no), per rehabilitation type (remediation standard applied) and compared with one another and against the Reference Area.

Since only Lot C Contractor applied different remediation technologies, survivorship additionally was compared for soils predominately treated using Thermal Desorption or Bio-remediation technologies.

WIDTH GROWTH (high/low Irrigation) – Lot A

Reference Area	*Rhanterium epapposum*		*Nitraria retusa*		*Panicum turgidum*		*Cyperus conglomeratus*		*Astragalus spinosus**	
Irrigation Level	High	Low	High	Low	High	Low	High	Low	High	Low
At Planting	34.58	39.58	3.08	3.33	33.33	43.50	29.33	29.33	4.46	4.50
End of Monitoring Period (cm)	57.00	62.73	20.00	16.63	56.67	52.22	40.00	45.91	28.75	30.00
Total Average Growth (cm)	22.42	23.14	16.92	13.29	23.33	8.72	10.67	16.58	24.29	25.50
Total Average Growth	+65%	+58%	+550 %	+300 %	+70%	+20%	+36%	+57%	+545 %	+467 %

Remediated Area	*Rhanterium epapposum*		*Nitraria retusa*		*Panicum turgidum*		*Cyperus conglomeratus*		*Prosopis farcta**	
Irrigation Level	High	Low	High	Low	High	Low	High	Low	High	Low
At Planting (cm)	12.12	10.78	3.46	3.12	22.26	23.51	16.66	16.97	14.94	15.20
End of Monitoring Period (cm)	31.68	29.64	12.32	12.12	71.69	76.14	30.07	30.52	70.74	60.05
Total Average Growth (cm)	19.56	18.86	8.86	9.01	49.42	52.63	13.41	13.55	55.81	44.85
Total Average Growth	+161%	+175%	+256%	+289%	+222%	224%	+80%	+80%	+374%	+295%

Survivorship (high/low Irrigation) – Lot C

Survivorship per Species in %

	Rhanterium epapposum		*Nitraria Retusa*		*Panicum turgidum*		*Cyperus conglomeratus*		*Astragalus spinosus**		*Prosopis farcta**	
Irrigation Level	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**	**High**	**Low**
Reference Area	100	100	8	75	100	75	92	100	96	100	N/A	N/A
Sludge Pit C1 (Primary Remediation Standard)	42	22	0	0	43	38	40	15	N/A	N/A	37	36
Effluent Pit C3 (Primary Remediation Standard)	16	5	7	0	48	17	50	19	N/A	N/A	17	6
Effluent Pit C4 (Alternate Remediation Standard)	12	11	0	0	35	17	47	24	N/A	N/A	26	10

INITIAL & FINAL PLANTS' WIDTH

Comparison of plants' width growth in all 3 Lots

Feature	Planting Date	No amendments			With amendments			Final width: with vs. no amendments
		Initial Width	Final Width	Change	Initial Width	Final Width	Change	
LOT A Reference Area	10/12/12	19.5cm	41.4cm	+112.3%	N/A	N/A	N/A	N/A
EPA3 (Alternate RS)	11/12/14	13.8cm	45.8cm	+232.6%	10.6cm	71.6cm	+575.0%	+56.3%
EPA4 (Primary RS)	03/12/14	18.9cm	27.7cm	+46.8%	19.0cm	36.9cm	+94.0%	+33.2%
SPA1 (Primary RS)	23/11/14	11.8cm	59.2cm	+402.7%	11.6cm	74.8cm	+546.1%	+26.4%
LOT B Reference Area	11/12/12	29.7cm	41.4cm	+39.1%	N/A	N/A	N/A	N/A
EPB2 (Alternate RS)	15/12/14	53.2cm	44.6cm	-16.2%	51.9cm	56.6cm	+9.1%	+26.9%
EPB3 (Primary RS)	03/02/15	45.5cm	47.8cm	+5.1%	41.5cm	53.6cm	+29.0%	+12.1%
SPB1 (Primary RS)	17/02/15	48.1cm	59.2cm	+22.9%	46.3cm	70.9cm	+53.1%	+19.8%
LOT C Reference Area	09/12/12	20.7cm	60.2cm	+190.8%	N/A	N/A	N/A	N/A
EPC3 (Primary RS)	22/11/14	23.0cm	44.7cm	+94.4%	24.5cm	43.8cm	+78.3%	-2.0%
EPC4 (Alternate RS)	27/11/14	18.1cm	37.3cm	+105.6%	18.0cm	51.2cm	+184.4%	+37.3%
SPC1 (Primary RS)	09/11/14	16.9cm	78.7cm	+366.4%	16.9cm	70.8cm	+318.5%	-11.2%

Lot A/Lot C have used different plant nurseries. In general, Lot B plants have been substantially better grown prior to planting than Lot A/C plants. This may have affected achievable final width and survivorship rates.

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PLANTS' SURVIVORSHIP – LOT A

Feature	No amendments			With amendments			Average in remediated soils
	High Irrigation	Low Irrigation	Average	High Irrigation	Low Irrigation	Average	
Ref Area	55.56%	81.94%	68.75%	N/A	N/A	N/A	N/A
EPA3 (Alternate RS)	44.91%	23.73%	34.32%	44.79%	31.83%	38.31%	36.32%
EPA4 (Primary RS)	40.63%	31.37%	36.00%	37.15%	34.26%	35.71%	35.85%
SPA1 (Primary RS)	28.24%	17.59%	22.92%	59.31%	51.47%	55.39%	39.15%
Average by Irrigation	37.92%	24.23%		47.09%	39.19%		
Average by Amendment			31.08%			43.14%	
Average in remediated soils							37.11%

- Compared to reference area remediated soils provide less ecological functionality. Survivorship in remediated soils achieves 54% of reference area.
- In high irrigation areas survivorship is 34% higher than in low irrigation areas.
- Survivorship rate in areas with amendments is 38% higher than in areas with no amendments.
- Application of soil amendments increases survivorship in low irrigation areas by 62% (24% in high irrigation areas).
- Marginal difference between soils remediated to Alternate RS (36%) and soils treated to Primary RS (average 38%).

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PLANTS' SURVIVORSHIP – LOT B

Feature	No amendments			With amendments			Average in remediated soils
	High Irrigation	Low Irrigation	Average	High Irrigation	Low Irrigation	Average	
Ref Area	45.83%	34.72%	40.28%	N/A	N/A	N/A	N/A
EPB2 (Alternate RS)	80.32%	67.94%	74.13%	77.31%	64.58%	70.95%	72.54%
EPB3 (Primary RS)	76.50%	63.08%	69.79%	82.06%	73.96%	78.01%	73.90%
SPB1 (Primary RS)	90.74%	89.35%	90.05%	86.11%	81.94%	84.03%	87.04%
Average by Irrigation	82.52%	73.46%		81.83%	73.50%		
Average by Amendment			77.99%			77.66%	
Average in remediated soils							77.82%

- Compared to reference area remediated soils provide significantly more ecological functionality (average survivorship in reference area 40%, in remediated soils 78%).
- In high irrigation areas survivorship is 12% higher than in low irrigation areas.
- No difference in survivorship rates in areas with and without amendments.
- Application of soil amendments does not result in different survivorship rates in high or low irrigation areas.
- Survivorship in soils remediated to Alternate RS (73%) is 10% lower than in soils t reated to Primary RS (80%).

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PLANTS' SURVIVORSHIP – LOT C

Feature	No amendments			With amendments			Average in remediated soils
	High Irrigation	Low Irrigation	Average	High Irrigation	Low Irrigation	Average	
Ref Area	81.94%	91.67%	86.81%	N/A	N/A	N/A	N/A
EPC3 (Primary RS)	20.37%	9.61%	14.99%	30.44%	11.23%	**20.83%**	**17.91%**
EPC4 (Alternate RS)	32.92%	12.43%	22.67%	22.15%	10.56%	**16.35%**	**17.91%**
SPC1 (Primary RS)	23.98%	20.28%	22.08%	39.17%	22.78%	30.97%	35.30%
Average by Irrigation	30.71%	20.49%		30.48%	12.62%		
Average by Amendment			25.60%			21.47%	
Average in remediated soils							23.57%

- Compared to reference area remediated soils provide significantly less ecological functionality. Survivorship in remediated soils achieves 27% of reference area.
- In high irrigation areas survivorship is 85% higher than in low irrigation areas.
- Survivorship rate in areas with amendments is 16% less than in areas without amendments. Application of soil amendments lowers survivorship rates in both low and high irrigation areas.
- Survivorship in soils bio-remediated to Alternate RS is 32% lower than the average survivorship in soils treated to Primary RS (using Thermal Desorption).

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PLANTING SURVIVORSHIP COMPARASION

Project	Reference Vs Remediated Soil	High and low irrigation blocks	With and Without soil amendments
LOTA	Reference Area fared better.	No significant difference barring few species.	No significant difference.
LOT B	Remediated Soil area fared better.	No significant difference barring one species.	No difference.
LOT C	Reference Area fared better.	High irrigation performed better than low irrigation blocks	• Plants in amended soils show a slightly better survivorship in amended soils (all species) except for EPC4. • Plants in exclusively bio-treated soils (EPC4 => Alternate Ecotoxicity Remediation Standard) show a significant less survivorship with amendments applied (all species).

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Ecological Experimental Results

- 3 Sludge and 6 Effluent Pits
  - Plant survivorship in remediated soils at the end of experiment period: 56%
  - Plant growth and survivorship in remediated areas slightly lower than in not contaminated soils in Control Areas and Gatch Pits;
  - Soil amendments do not significantly improve plants' growth and survivorship;
  - Rehabilitation improves re-settlement of natural plants and wild-life.

Irrigation Tube

Lessons Learnt and Conclusions

Lot A

- Soil amendments have not significantly improved plants' survivorship compared to areas with no amendments applied.

Lot B

- Soil amendments have not made any difference in plants' survivorship compared to areas with no amendments applied.

Lot C

- Soil amendments significantly deteriorated plants' survivorship.

Overall

- No need to adopt soil amendments in future projects. .

Thank you
Q & A