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Distance-Based Linear Model Analysis of Groundwater Production Effects on Water Levels in Isolated Wetlands at the J.B. Starkey and North Pasco Regional Wellfields

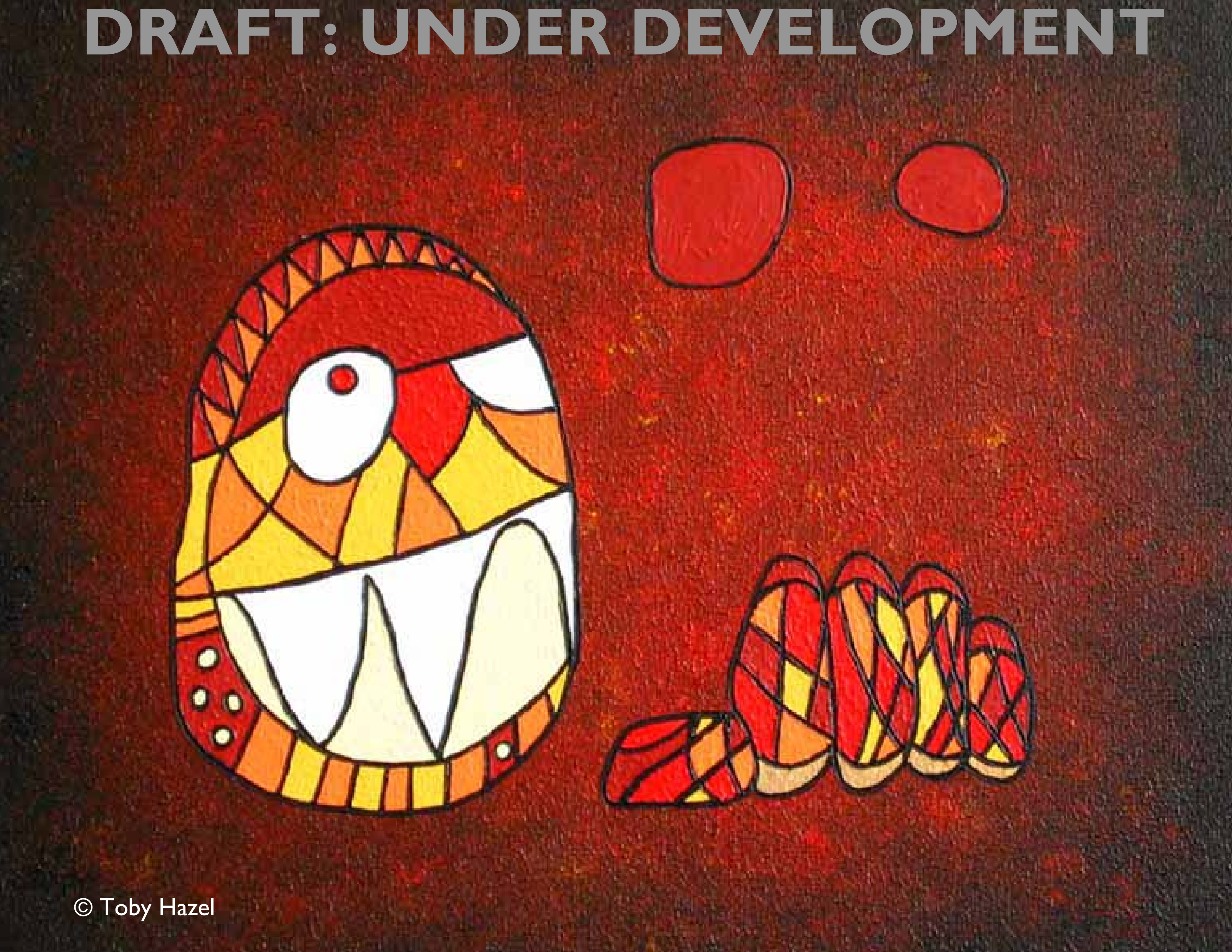
Dan Schmutz, M.S. and Diane Willis, M.S.

GPI Southeast, Inc.

February 13, 2008

Tampa Bay Water
Supplying Water To The Region

GPI



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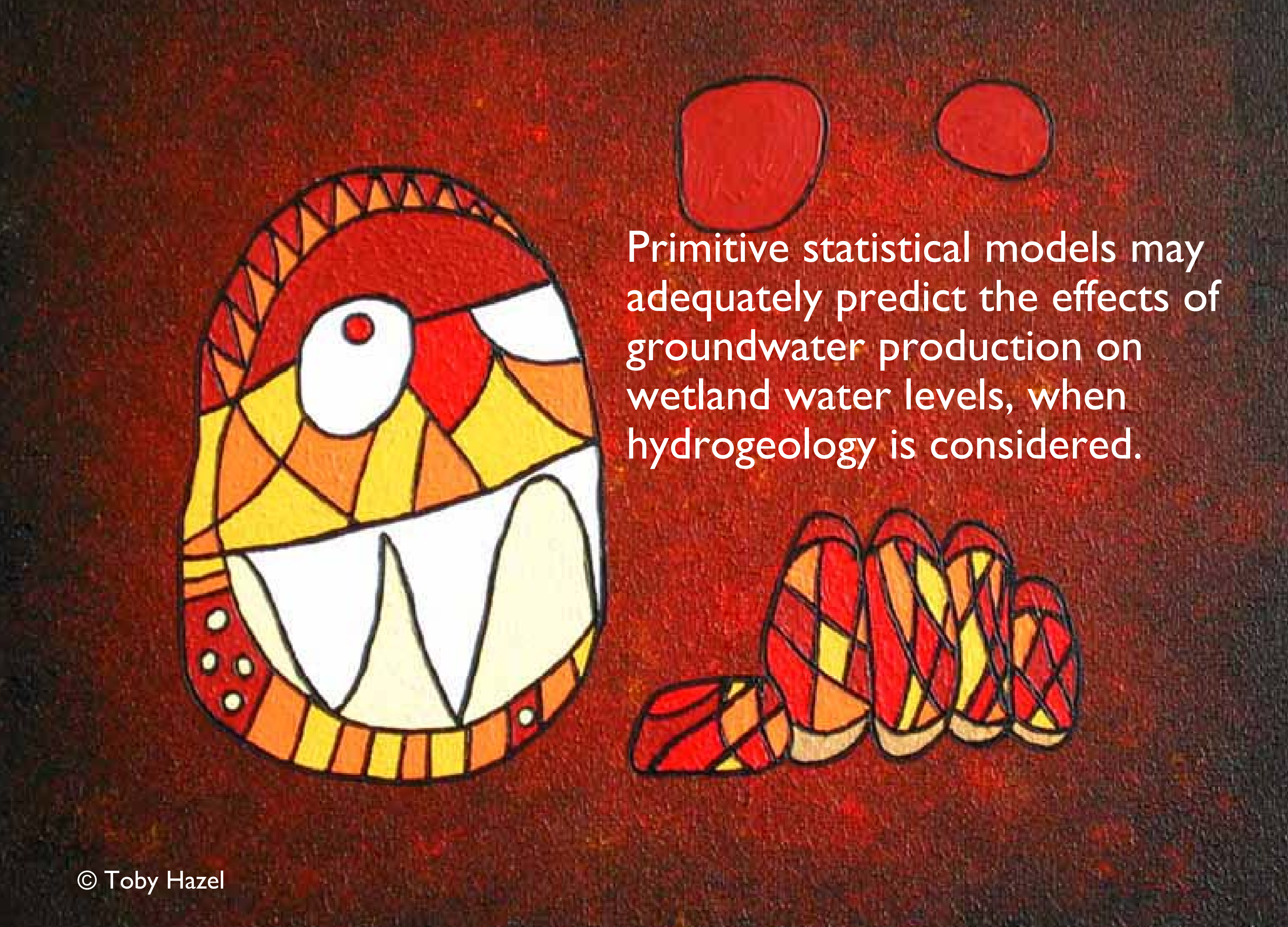

Primitive statistical models may adequately predict the effects of groundwater production on wetland water levels, when hydrogeology is considered.

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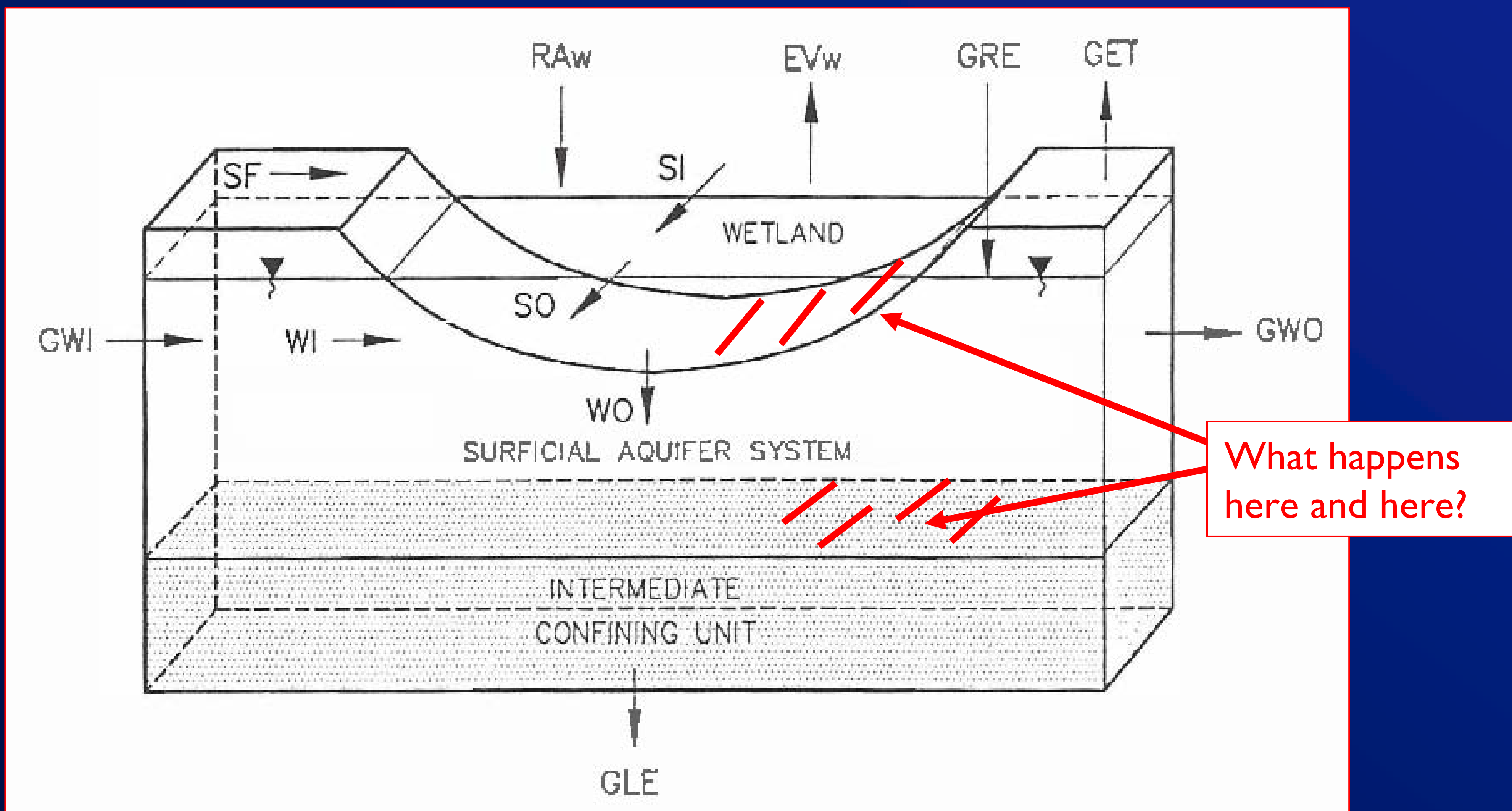
Why do we care?

Improved conceptual model of wetland function



(Berryman & Henigar, Inc. and SDI Environmental Services, Inc. 2000)

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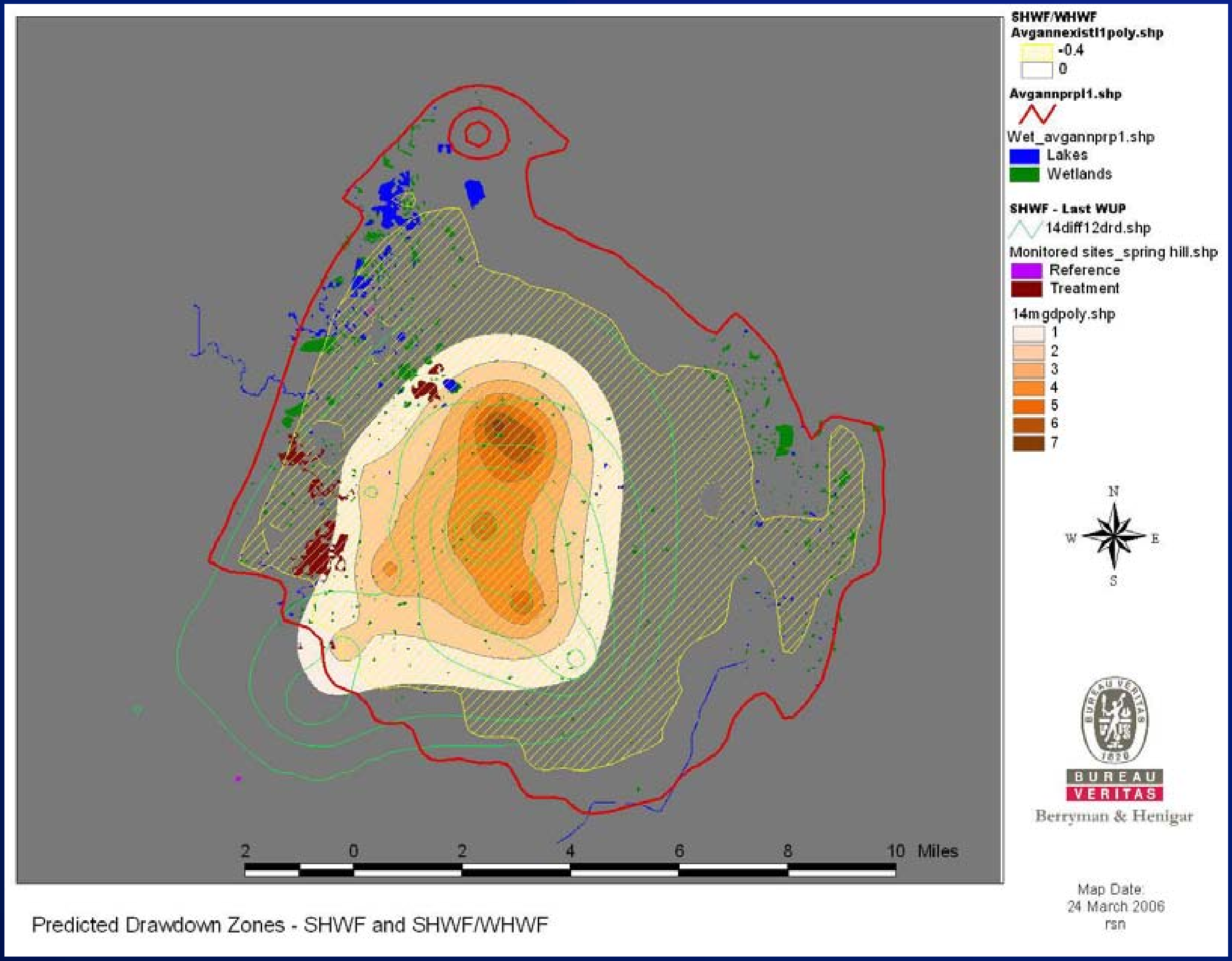
Improved water supply planning:
avoiding more vulnerable wetlands in wellfield design



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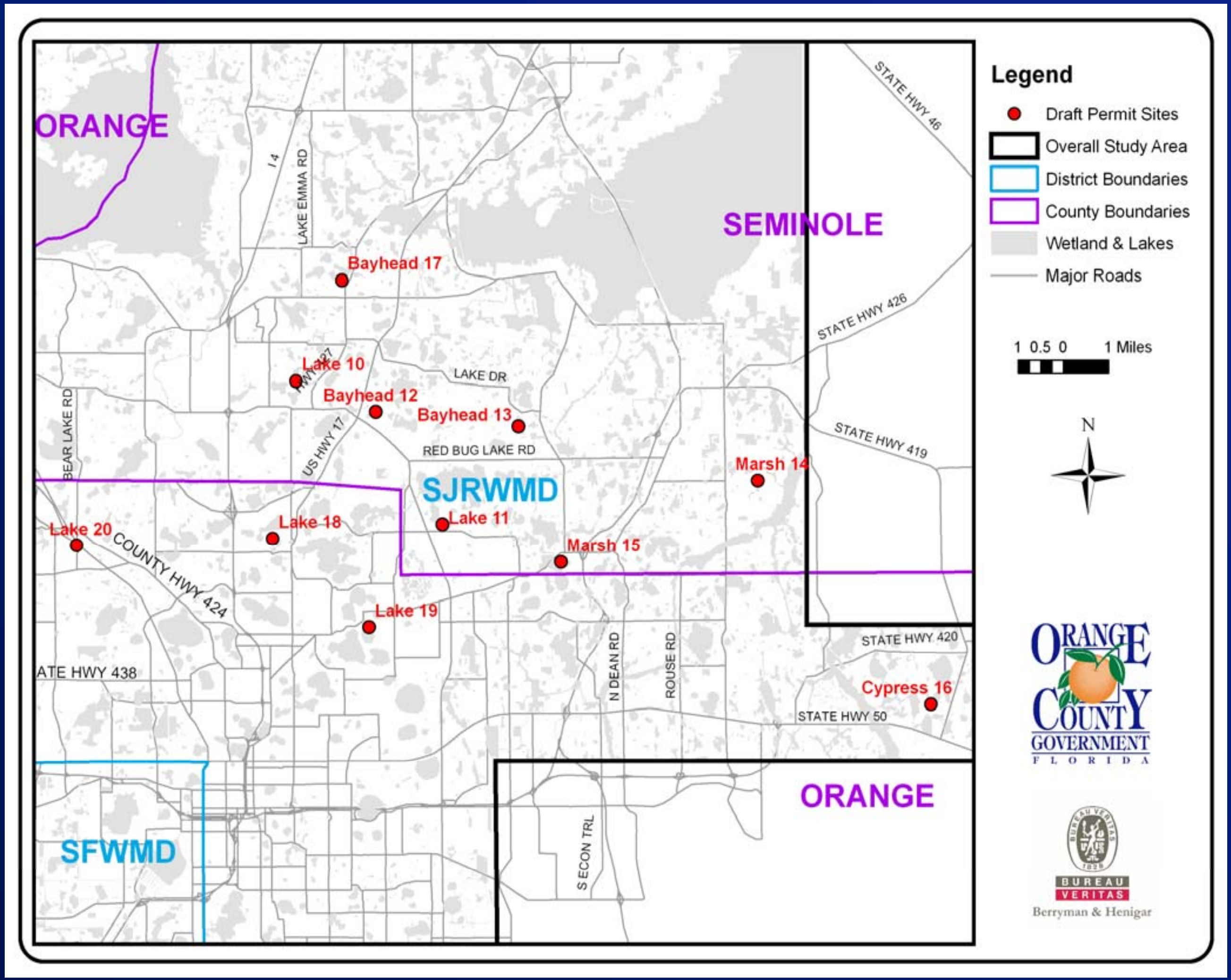
Improved monitoring site selection



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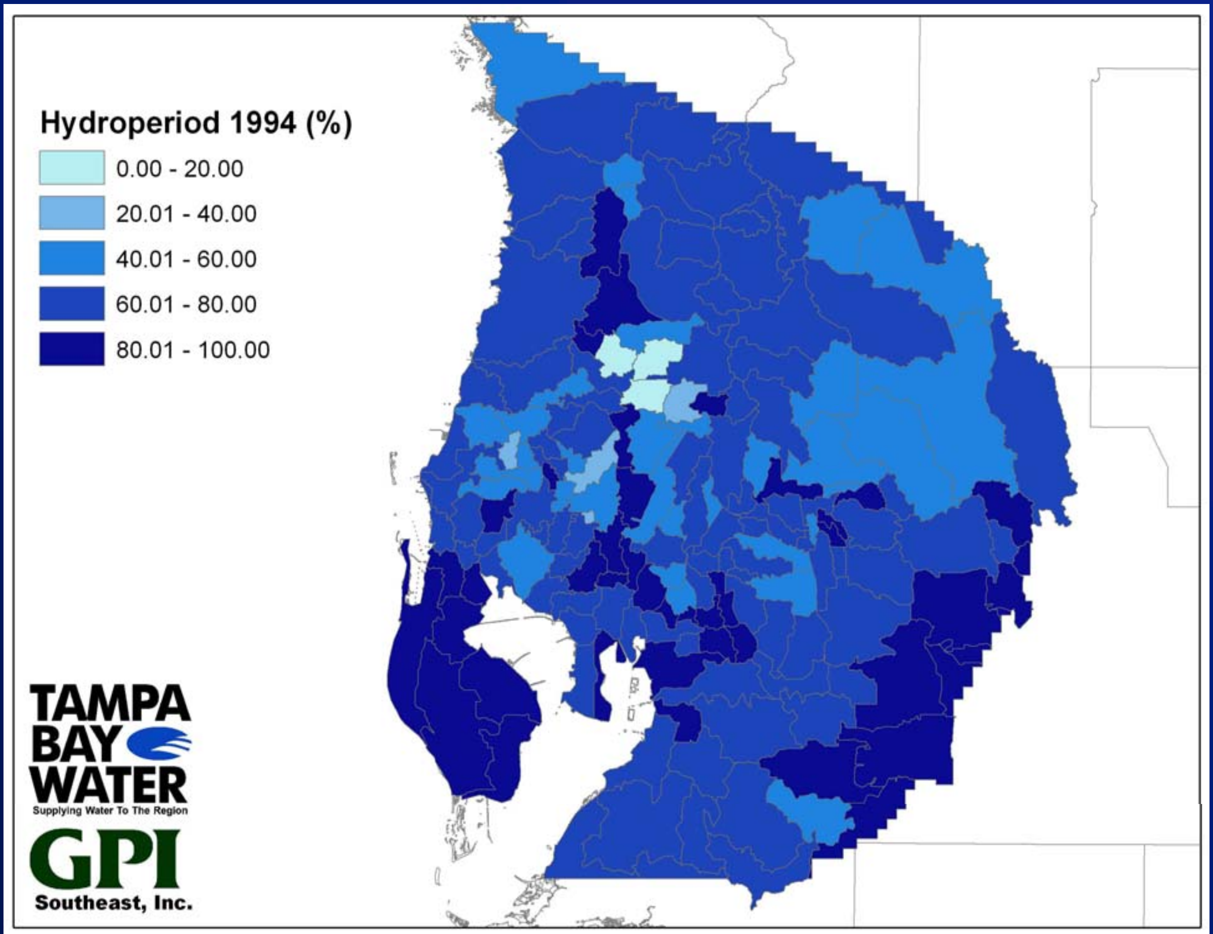
Improved understanding of landscape factors in the Integrated Northern Tampa Bay Hydrologic Model



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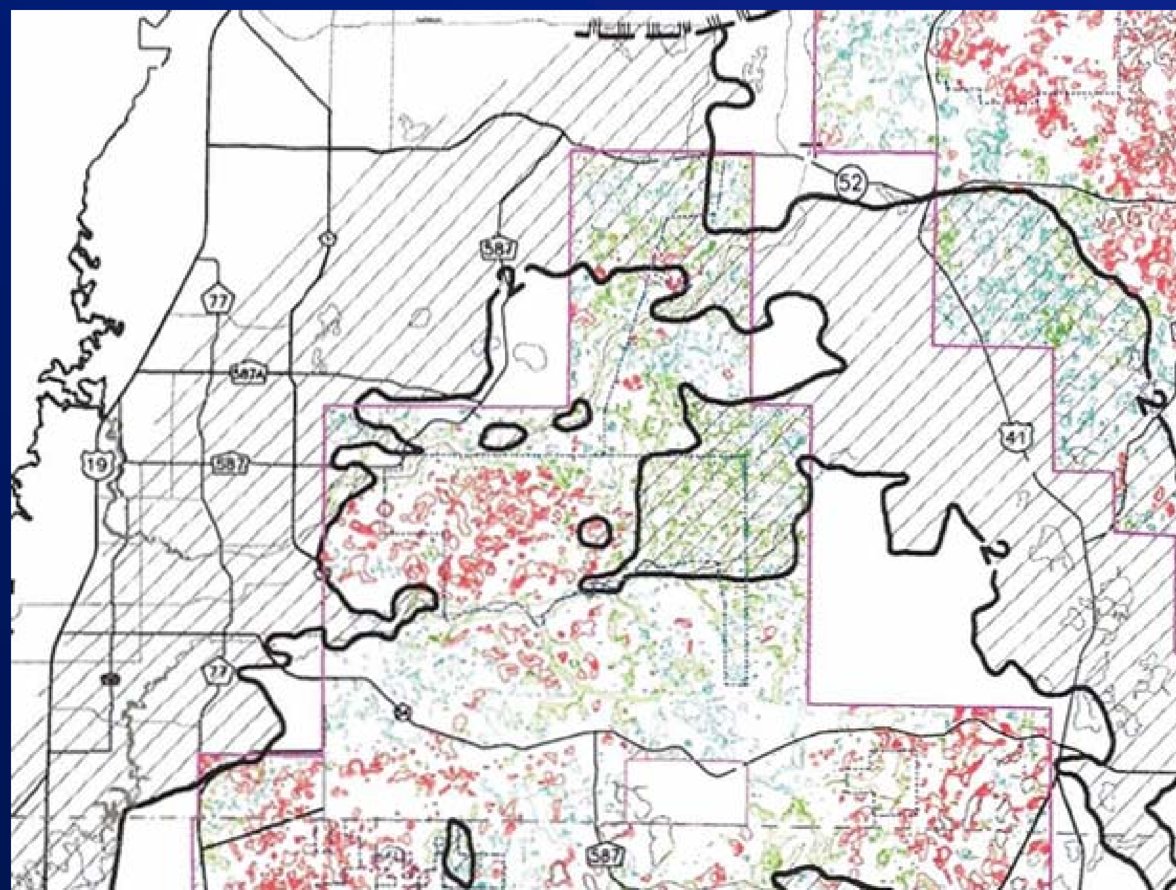
Improved null hypothesis for impact detection for regions lacking sophisticated hydrologic models



(Berryman & Henigar, Inc. and SDI Environmental Services, Inc. 2000)

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Research Questions

- Is a distance-based groundwater production effect present in any particular year?
- Does effect vary with hydrogeology?
- What is the relationship between rainfall and production effect?
- How far-reaching are effects during dry vs. wet year?


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Tale of Two Wetlands
S-39
S-36A

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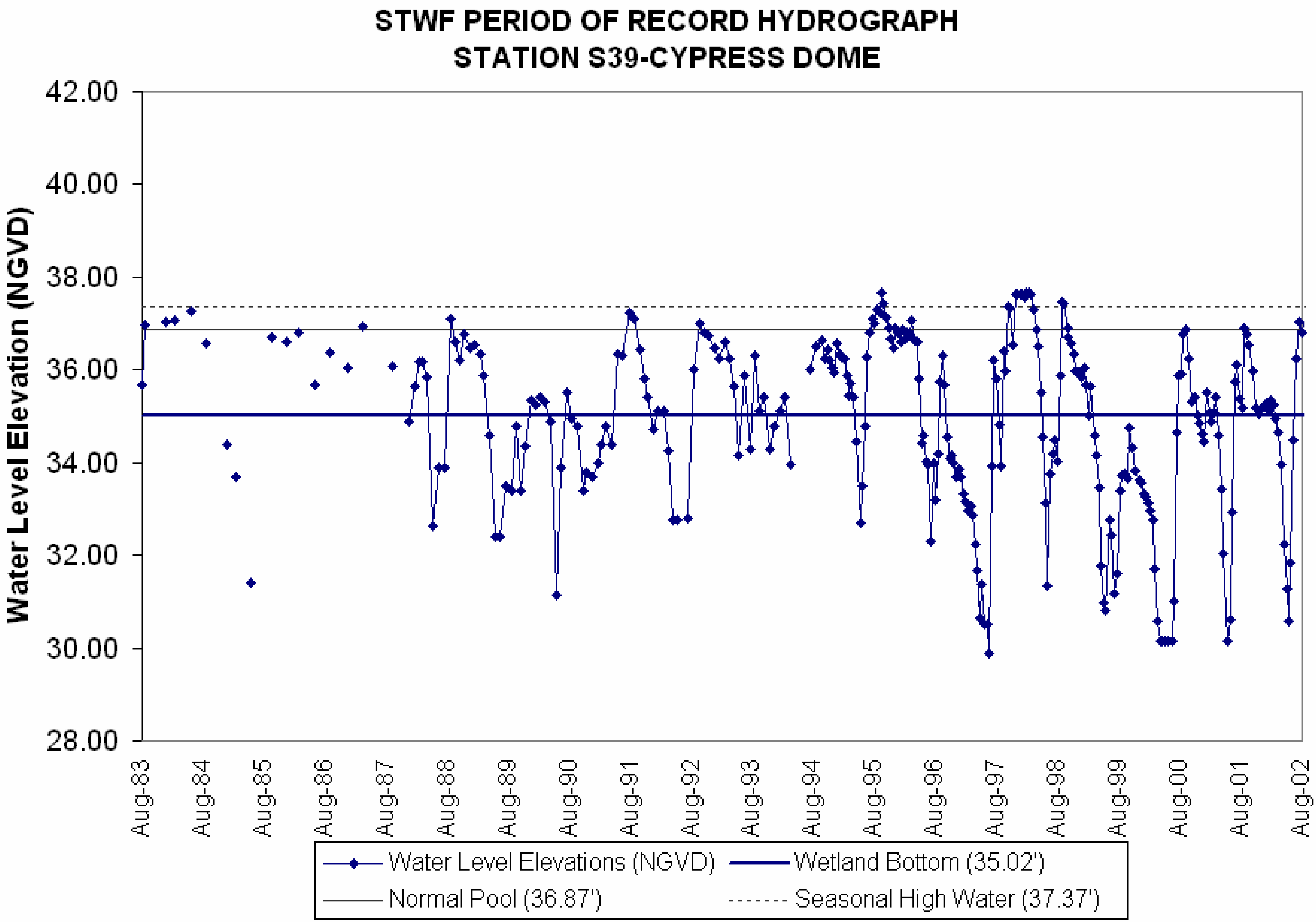

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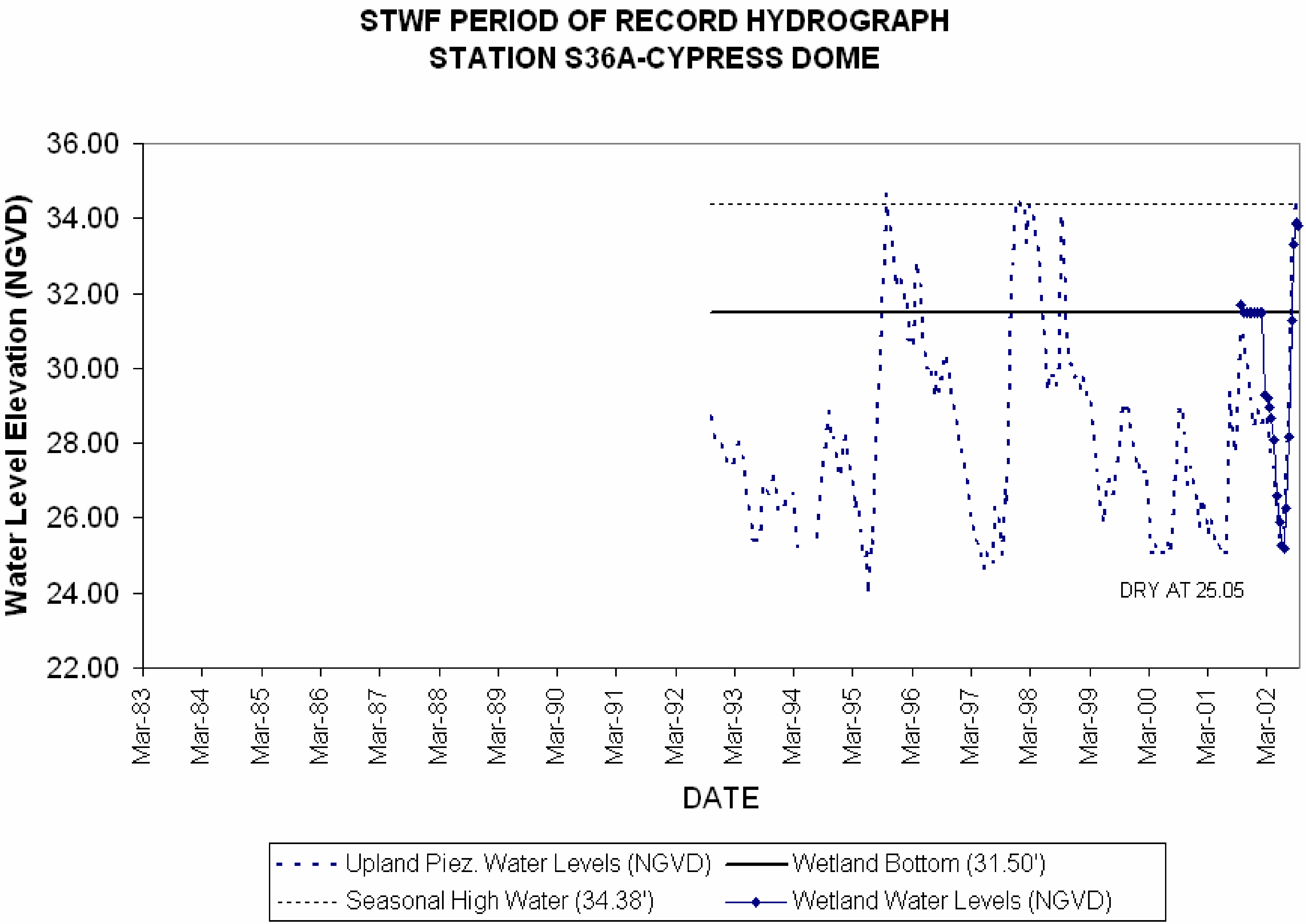

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Tale of Two Wetland Types

Xeric-associated

Mesic-associated


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Xeric-associated deep marsh in sand pine scrub matrix (west Starkey: S-18)


DRAFT: UNDER DEVELOPMENT
Mesic-associated shallow cypress in pine flatwoods matrix (east Starkey)

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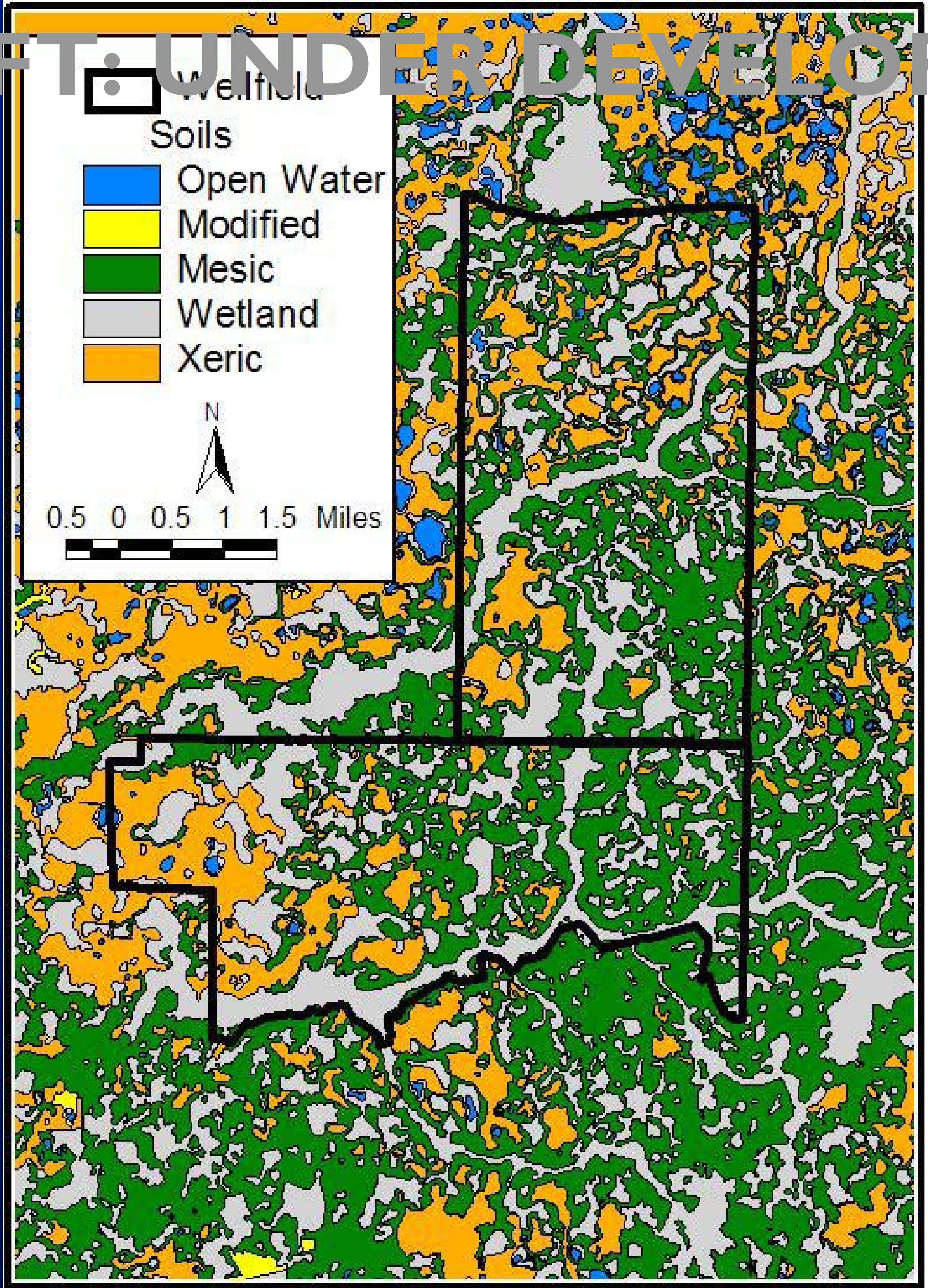

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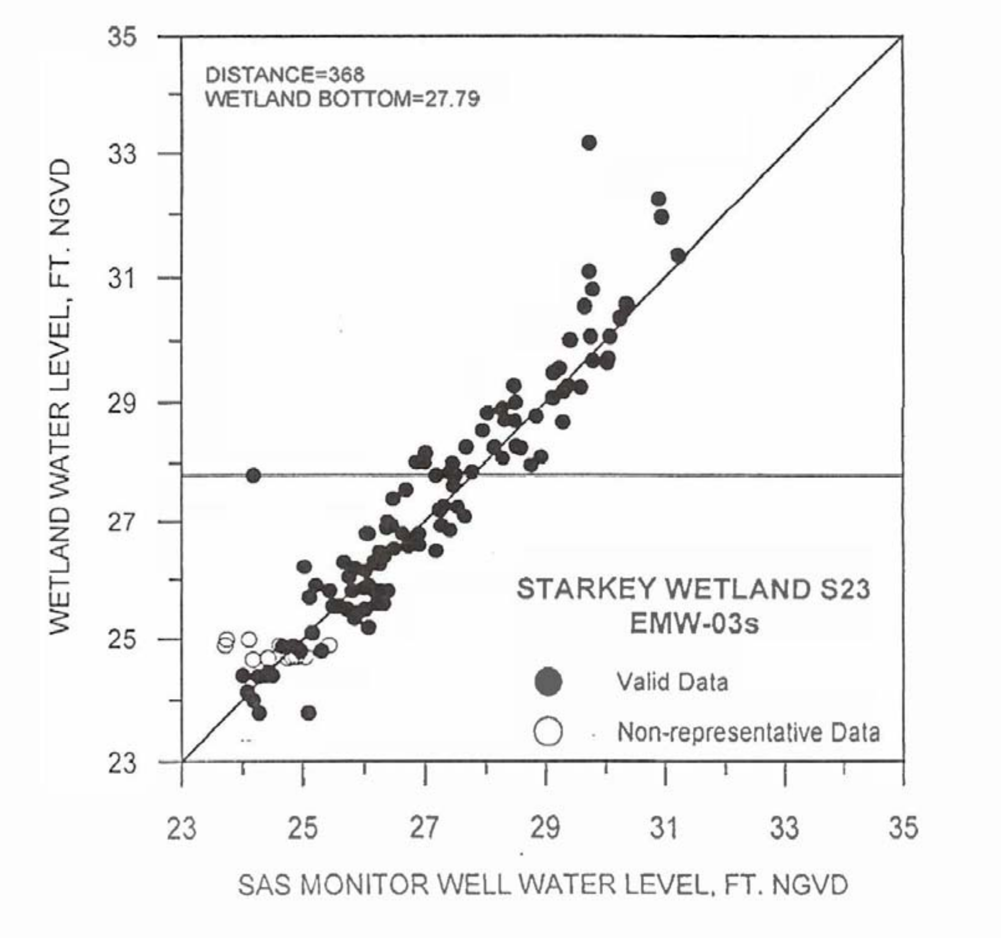
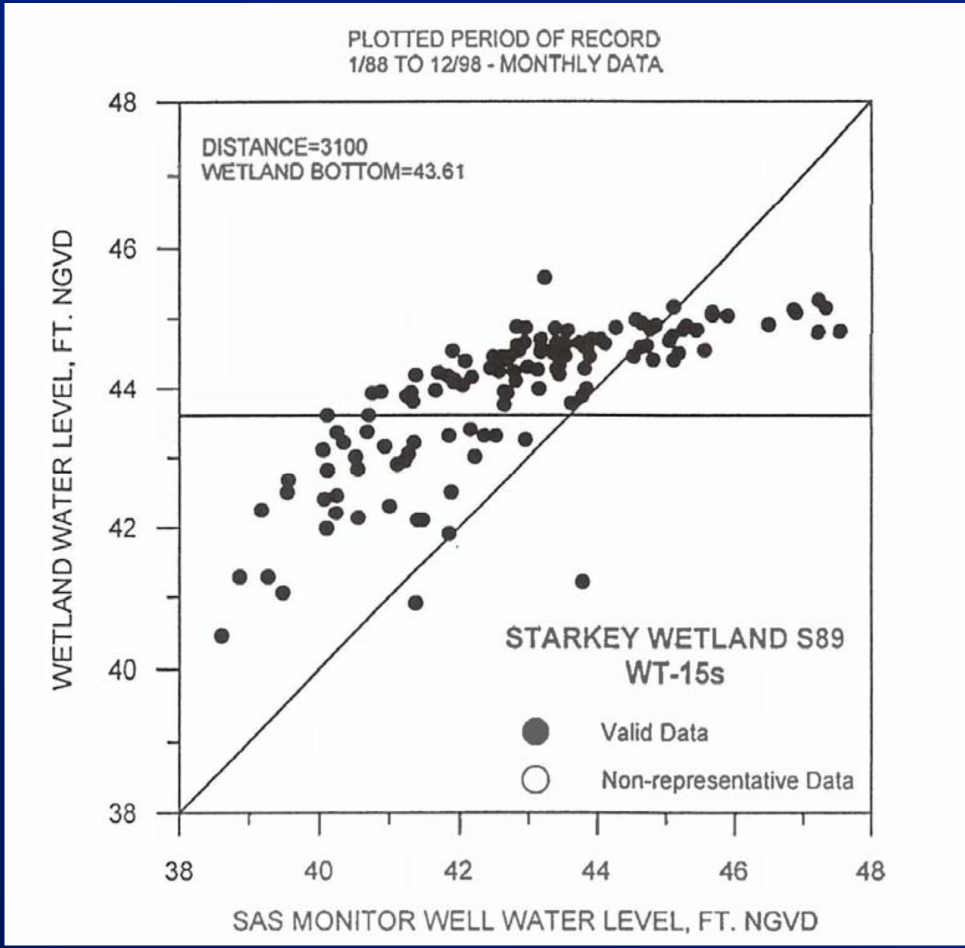
Tale of Two Wetland Types

Xeric-associated



Mesic-associated



(Berryman & Henigar, Inc. and SDI Environmental Services, Inc. 2000)

Methods

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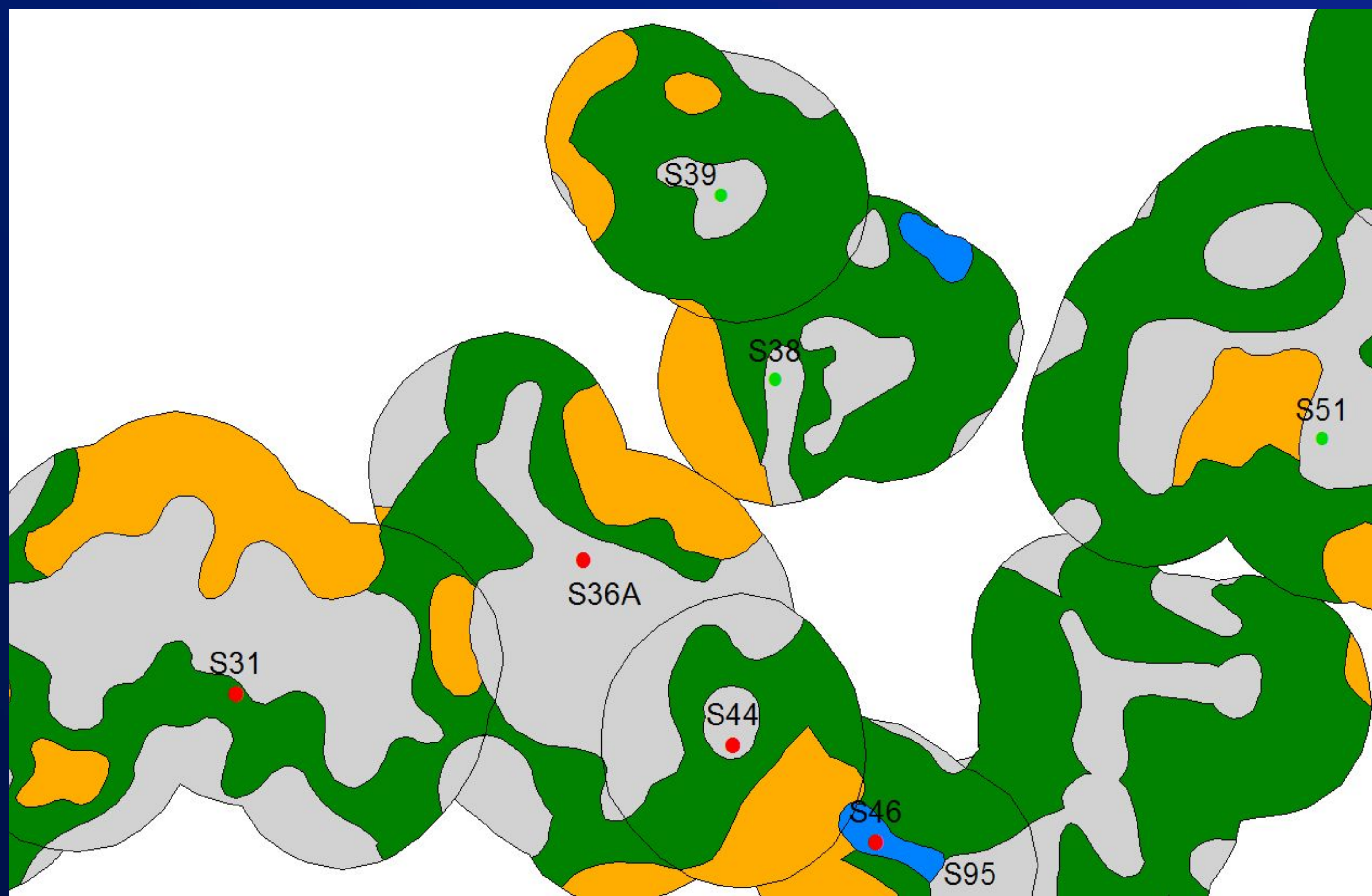
Determining Xeric/Mesic-association

- GIS buffer analysis (500 Ft)
- %Xeric = Areas (Xeric/(Xeric + Mesic))
- >27% Xeric = Xeric-associated



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Study Sites

- 79 isolated cypress and marsh sites
- 38 Xeric; 41 Mesic
- 6 to 13 years of data
- NPs or SHWs

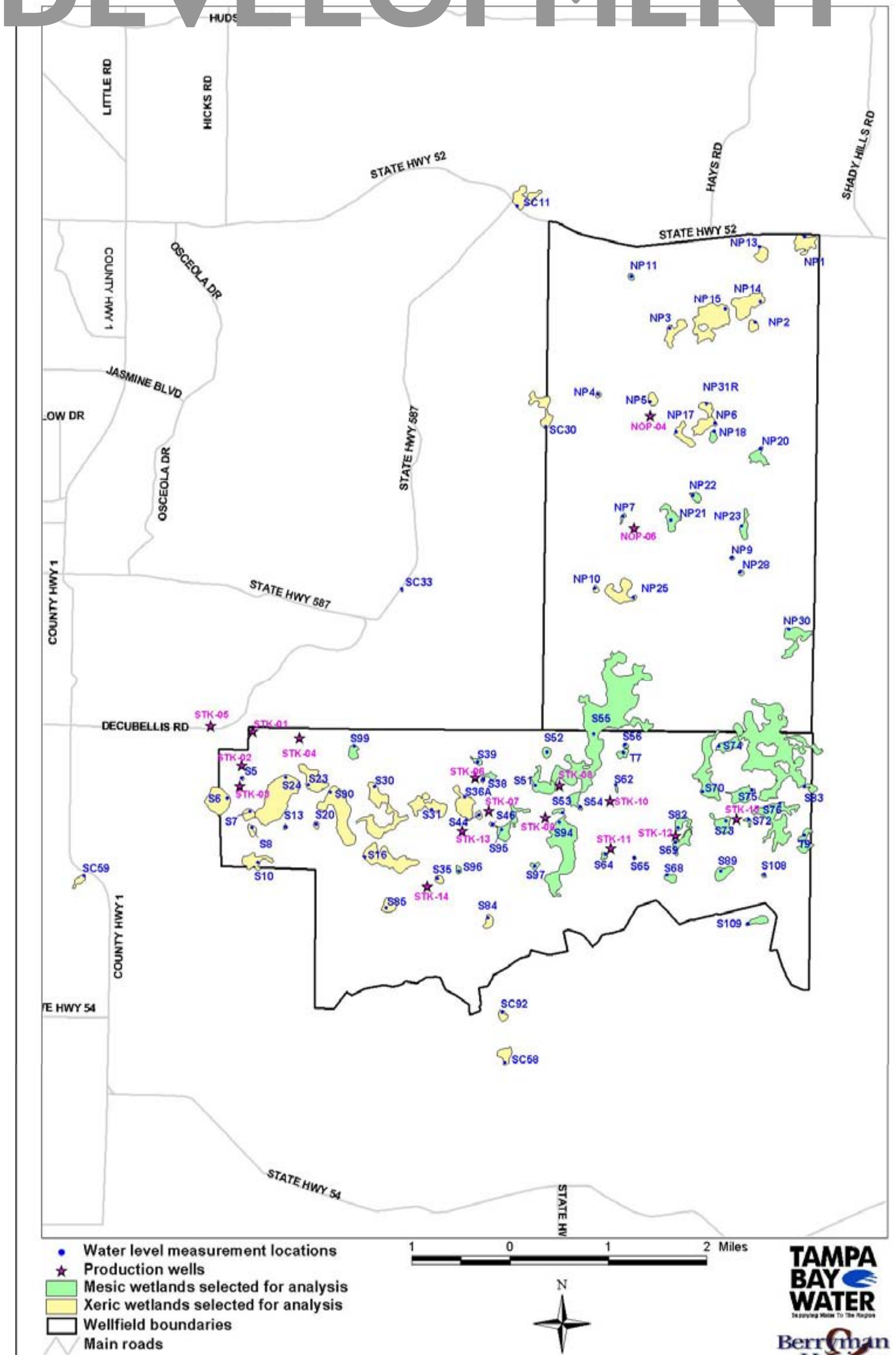

Figure 1: STWF and NPRWF Monitoring Sites Selected for Analysis

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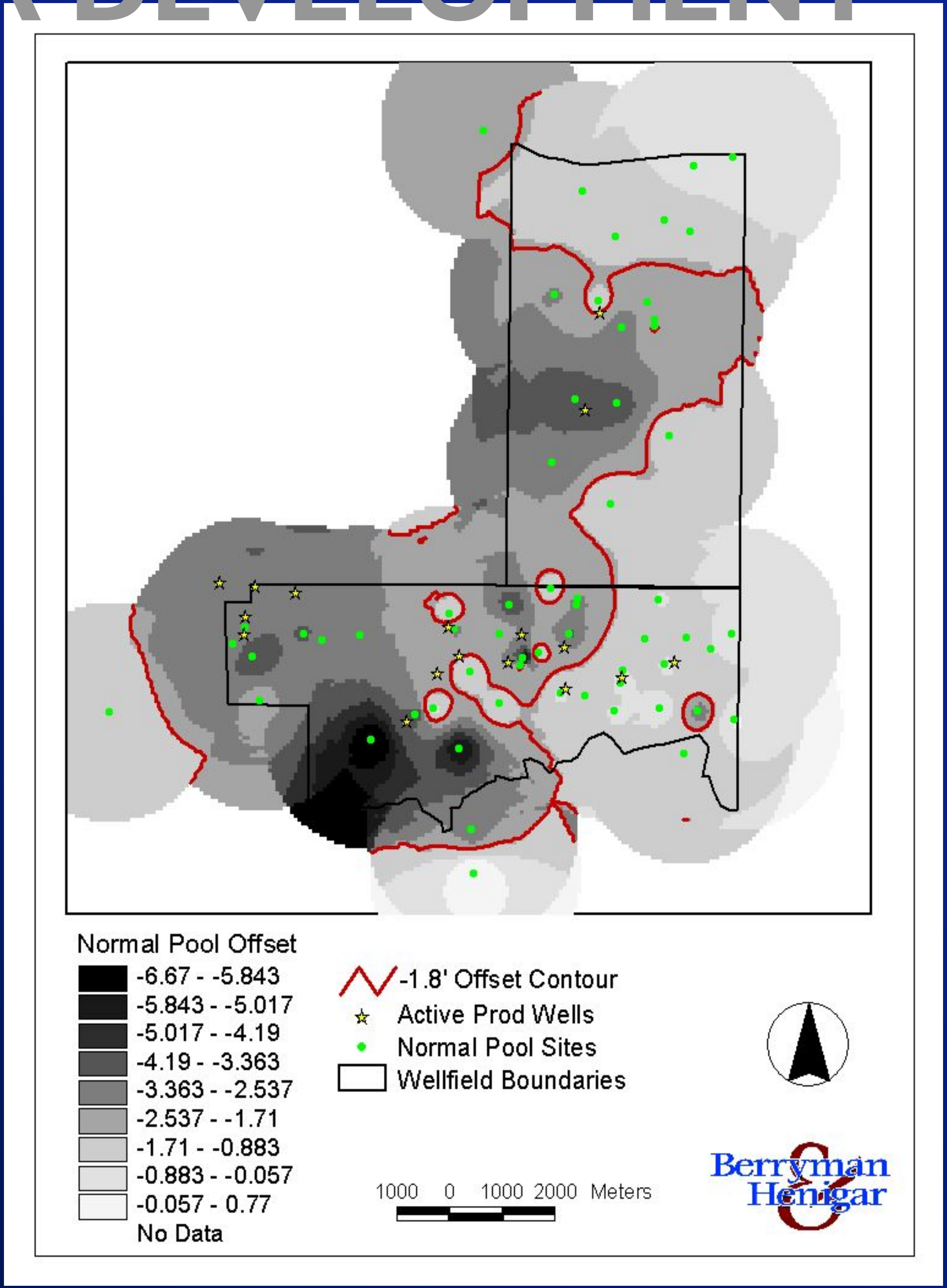
NP Offsets

- Removes elevation artifact and standardizes data
- Normal Pool subtracted from Last September observation for WY1990-WY2002



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Study Period Rainfall

Water Year	Dry Season	Wet Season	Annual Sum	Category
1990	22.33	32.06	54.39	
1991	30.02	33.66	63.68	weak El Nino
1992	14.59	30.65	45.24	weak La Nina
1993	31.19	23.23	54.42	
1994	**20.09**	**31.48**	**51.57**	**median rainfall**
1995	20.23	34.44	54.66	
1996	31.23	20.09	51.31	
1997	18.42	26.99	45.41	
1998	57.51	32.15	89.66	strong El Nino
1999	**12.57**	**26.31**	**38.88**	**strong La Nina**
2000	10.72	34.25	44.97	weak La Nina
2001	11.37	37.42	48.79	
2002	15.71	45.01	60.73	
Median	20.09	32.06	51.57	

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$$PWD = \sum_{i}^{n} \frac{Q_i}{\log_{10} D_i}$$

PWD = Production Weighted by Distance for particular wetland site-year

Q_i = Pumpage (millions of gallons per year) of well i

D_i = Distance (in feet) to well i

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Principle of Superposition

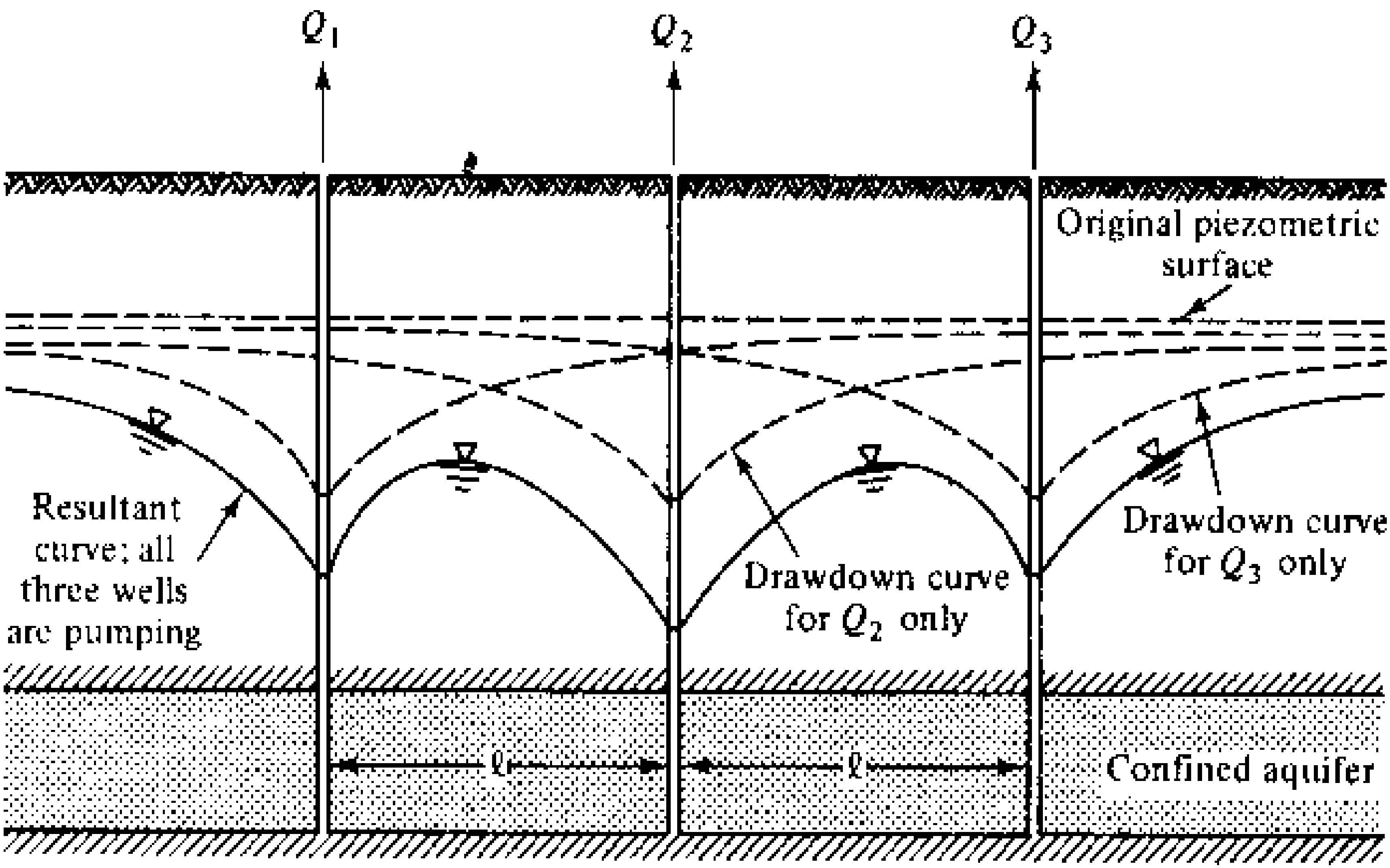

Figure 8-21 Individual and composite drawdown curves for three wells on a line.

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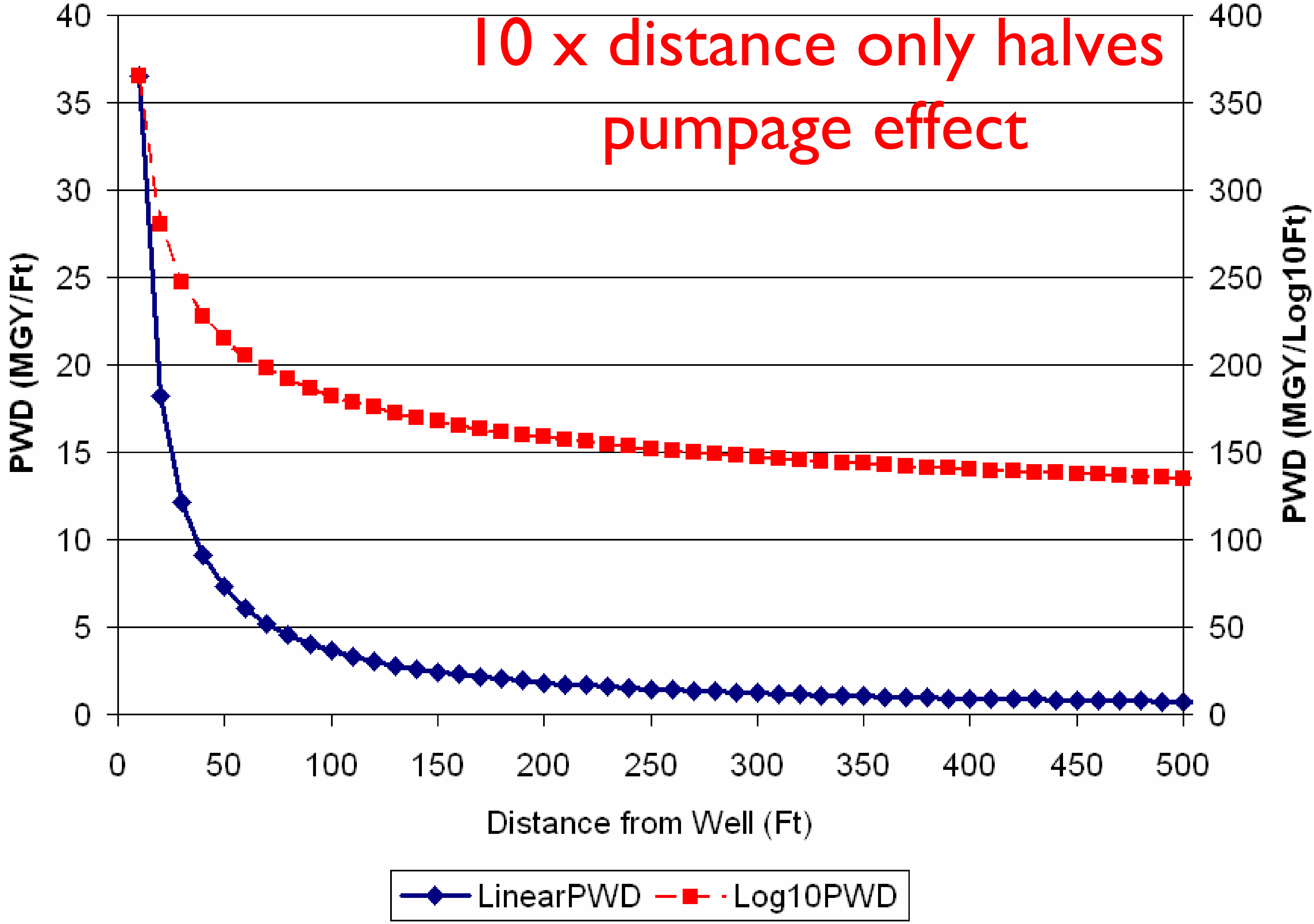

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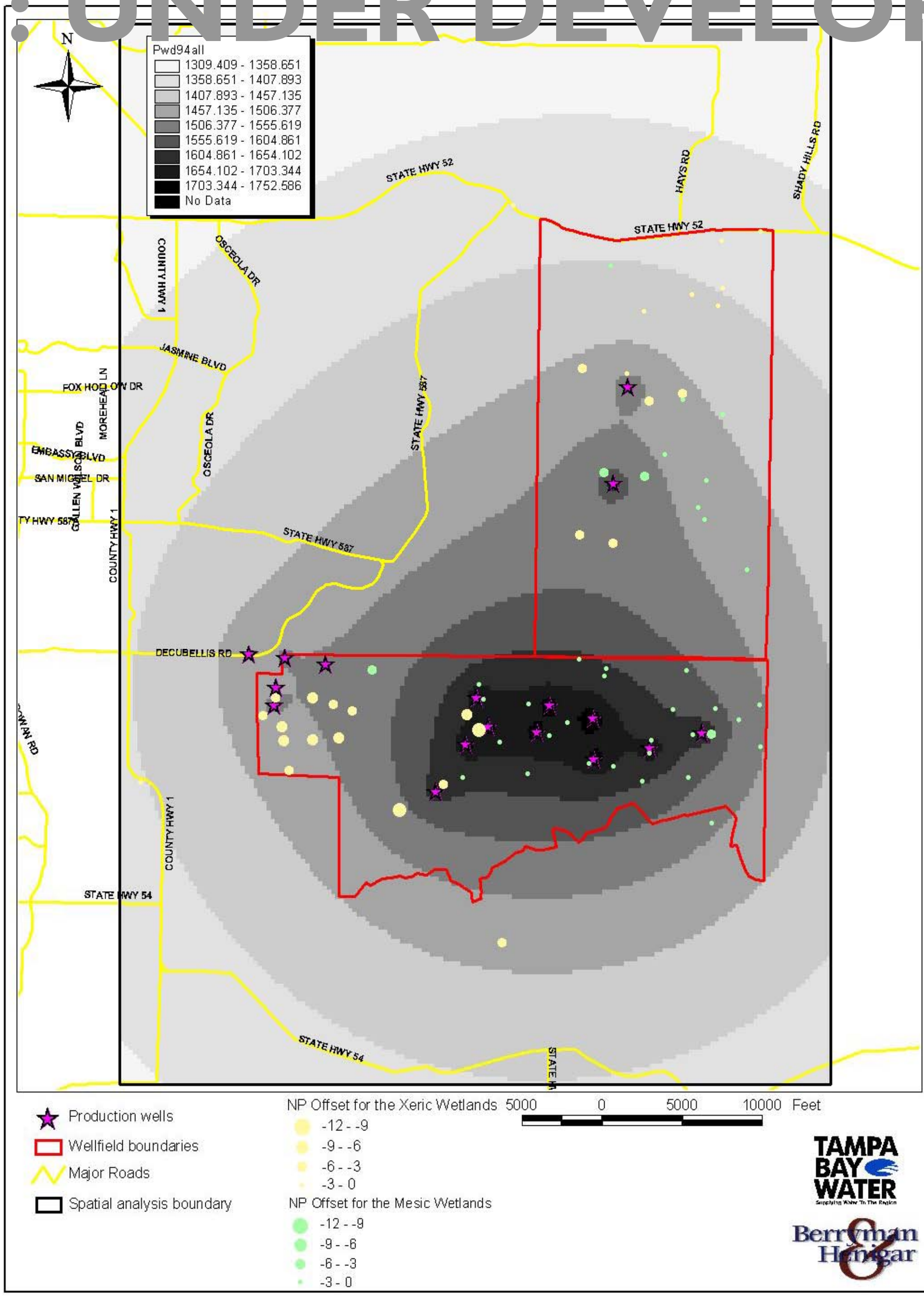

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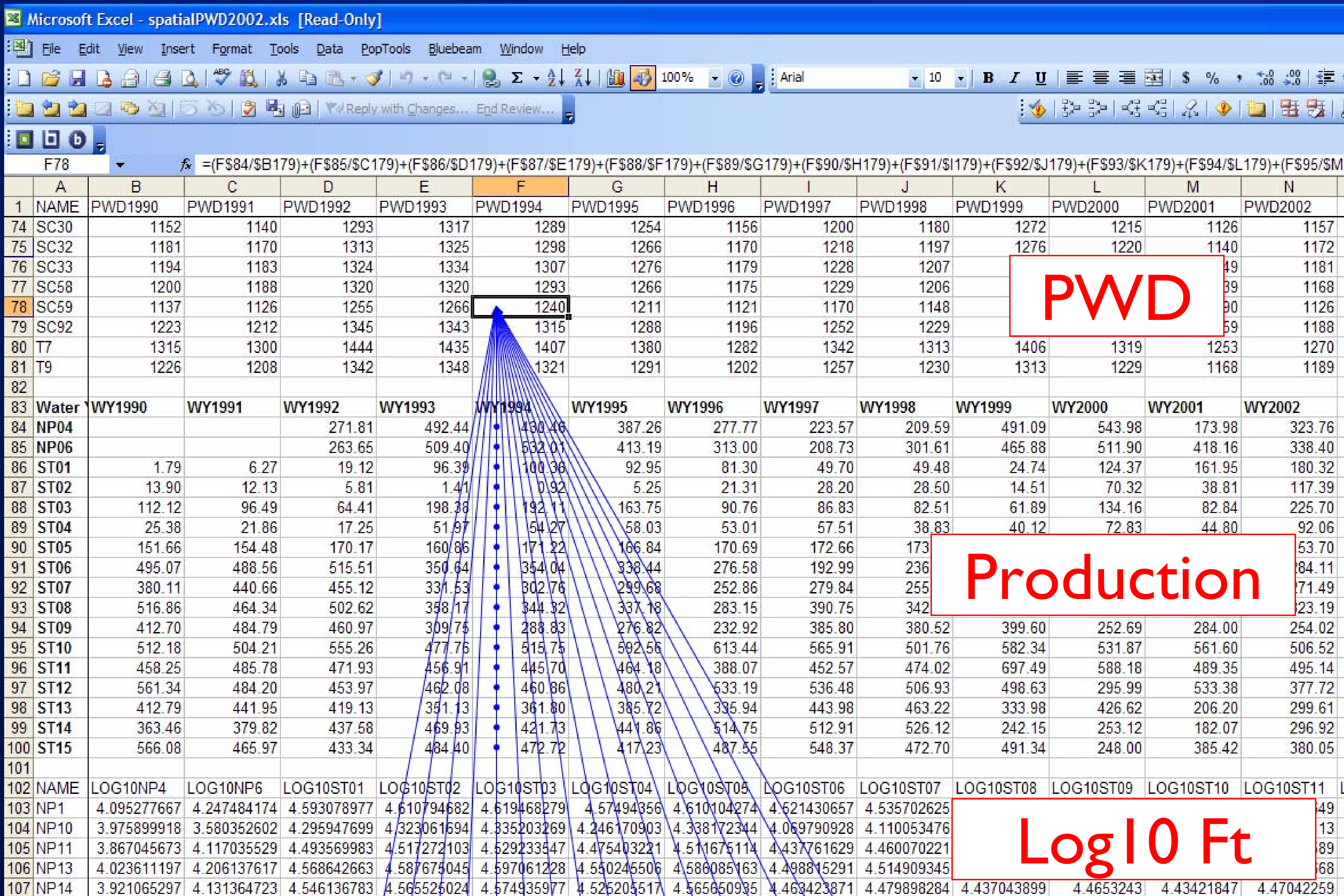
Calculating PWD with Spreadsheet



	A	B	C	D	E	F	G
1	NAME	PWD1990	PWD1991	PWD1992	PWD1993	PWD1994	PWD1995
74	SC30	1152	1140	1293	1317	1289	1254
75	SC32	1181	1170	1313	1325	1298	1266
76	SC33	1194	1183	1324	1334	1307	1276
77	SC58	1200	1188	1320	1320	1293	1266
78	SC59	1137	1126	1255	1266	1240	1211
79	SC92	1223	1212	1345	1343	1315	1288
80	T7	1315	1300	1444	1435	1407	1380
81	T9	1226	1208	1342	1348	1321	1291
82							
83	**Water Y**	**WY1990**	**WY1991**	**WY1992**	**WY1993**	**WY1994**	**WY1995**
84	**NP04**			271.81	492.44	430.46	387.26
85	**NP06**			263.65	509.40	532.01	413.19
86	**ST01**	1.79	6.27	19.12	96.39	100.36	92.95
87	**ST02**	13.90	12.13	5.81	1.41	0.92	5.25
88	**ST03**	112.12	96.49	64.41	198.38	192.11	163.75
89	**ST04**	25.38	21.86	17.25	51.97	54.27	58.03
90	**ST05**	151.66	154.48	170.17	160.86	171.22	166.84
91	**ST06**	495.07	488.56	515.51	350.64	354.04	338.44
92	**ST07**	380.11	440.66	455.12	331.53	302.76	299.68
93	**ST08**	516.86	464.34	502.62	358.17	344.32	337.18
94	**ST09**	412.70	484.79	460.97	309.75	288.83	276.82
95	**ST10**	512.18	504.21	555.26	477.76	515.75	592.56
96	**ST11**	458.25	485.78	471.93	456.91	445.70	464.18
97	**ST12**	561.34	484.20	453.97	462.08	460.86	480.21
98	**ST13**	412.79	441.95	419.13	351.13	361.80	385.72
99	**ST14**	363.46	379.82	437.58	469.93	421.73	441.86
100	**ST15**	566.08	465.97	433.34	484.40	472.72	417.23
101							
102	NAME	LOG10NP4	LOG10NP6	LOG10ST01	LOG10ST02	LOG10ST03	LOG10ST04
103	NP1	4.095277667	4.247484174	4.593078977	4.610794682	4.619468279	4.57494356
104	NP10	3.975899918	3.580352602	4.295947699	4.323061694	4.335203269	4.246170903
105	NP11	3.867045673	4.117035529	4.493569983	4.517272103	4.529233547	4.475403221
106	NP13	4.023611197	4.206137617	4.568642663	4.587675045	4.597061228	4.550245506
107	NP14	3.921065297	4.131364723	4.546136783	4.565525024	4.574935977	4.525205517

	A	H	I	J	K	L	M	N
1	NAME	PWD1996	PWD1997	PWD1998	PWD1999	PWD2000	PWD2001	PWD2002
74	SC30	1156	1200	1180	1272	1215	1126	1157
75	SC32	1170	1218	1197	1276	1220	1140	1172
76	SC33	1179	1228	1207	[illegible]	[illegible]	[illegible]	1181
77	SC58	1175	1229	1206	[illegible]	[illegible]	[illegible]	1168
78	SC59	1121	1170	1148	[illegible]	[illegible]	[illegible]	1126
79	SC92	1196	1252	1229	[illegible]	[illegible]	[illegible]	1188
80	T7	1282	1342	1313	1406	1319	1253	1270
81	T9	1202	1257	1230	1313	1229	1168	1189
82								
83	**Water Y**	**WY1996**	**WY1997**	**WY1998**	**WY1999**	**WY2000**	**WY2001**	**WY2002**
84	**NP04**	277.77	223.57	209.59	491.09	543.98	173.98	323.76
85	**NP06**	313.00	208.73	301.61	465.88	511.90	418.16	338.40
86	**ST01**	81.30	49.70	49.48	24.74	124.37	161.95	180.32
87	**ST02**	21.31	28.20	28.50	14.51	70.32	38.81	117.39
88	**ST03**	90.76	86.83	82.51	61.89	134.16	82.84	225.70
89	**ST04**	53.01	57.51	38.83	40.12	72.83	44.80	92.06
90	**ST05**	170.69	172.66	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
91	**ST06**	276.58	192.99	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
92	**ST07**	252.86	279.84	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
93	**ST08**	283.15	390.75	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
94	**ST09**	232.92	385.80	380.52	399.60	252.69	284.00	254.02
95	**ST10**	613.44	565.91	501.76	582.34	531.87	561.60	506.52
96	**ST11**	388.07	452.57	474.02	697.49	588.18	489.35	495.14
97	**ST12**	533.19	536.48	506.93	498.63	295.99	533.38	377.72
98	**ST13**	335.94	443.98	463.22	333.98	426.62	206.20	299.61
99	**ST14**	514.75	512.91	526.12	242.15	253.12	182.07	296.92
100	**ST15**	487.55	548.37	472.70	491.34	248.00	385.42	380.05
101								
102	NAME	LOG10ST05	LOG10ST06	LOG10ST07	LOG10ST08	LOG10ST09	LOG10ST10	LOG10ST11
103	NP1	4.610104274	4.521430657	4.535702625	[illegible]	[illegible]	[illegible]	[illegible]
104	NP10	4.338172344	4.069790928	4.110053476	[illegible]	[illegible]	[illegible]	[illegible]
105	NP11	4.511675114	4.437761629	4.460070221	[illegible]	[illegible]	[illegible]	[illegible]
106	NP13	4.586085163	4.498815291	4.514909345	[illegible]	[illegible]	[illegible]	[illegible]
107	NP14	4.565650935	4.463423871	4.479898284	4.437043899	4.4653243	4.43421847	4.47042259

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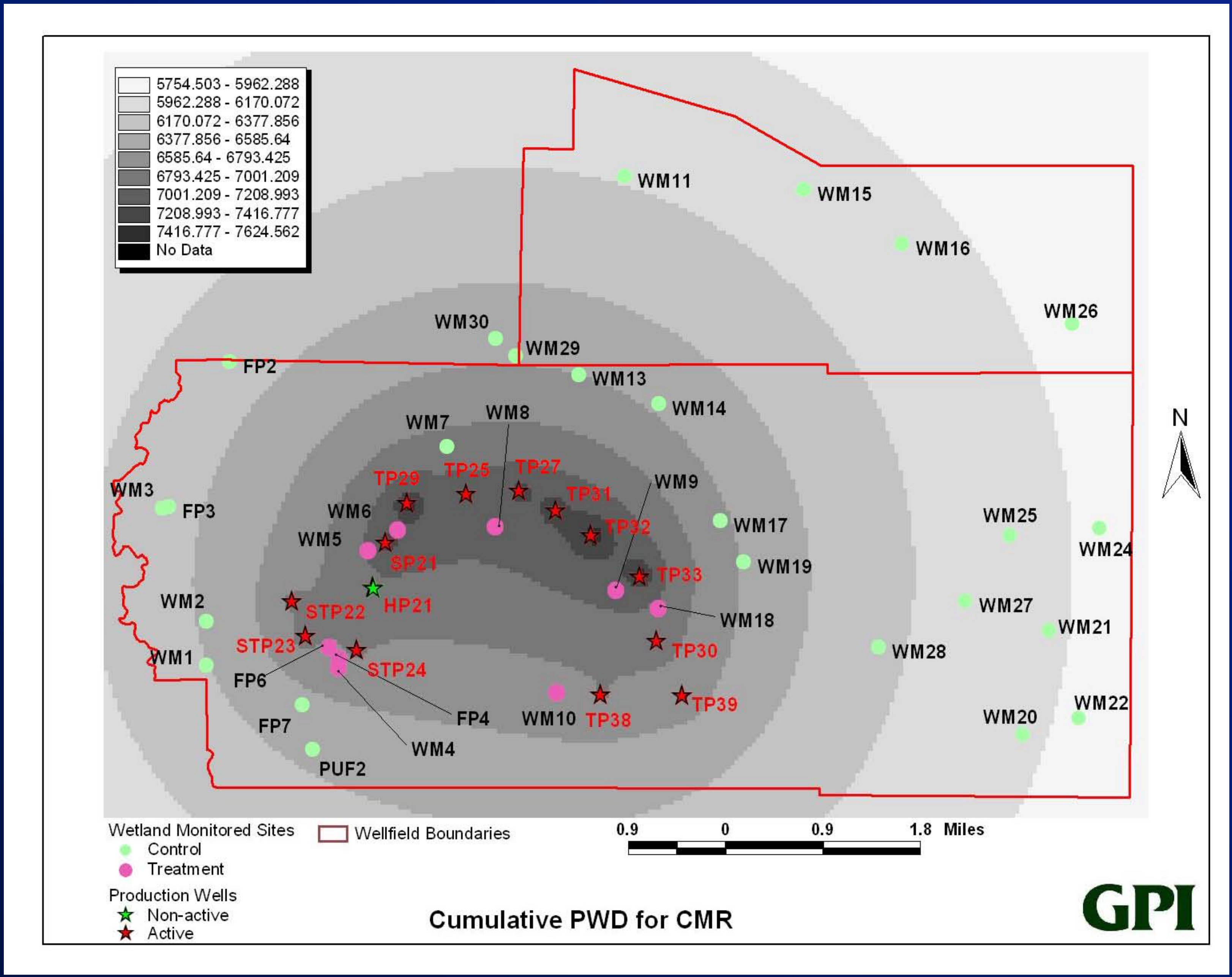
Calculating PWD with Raster Map Algebra



Results

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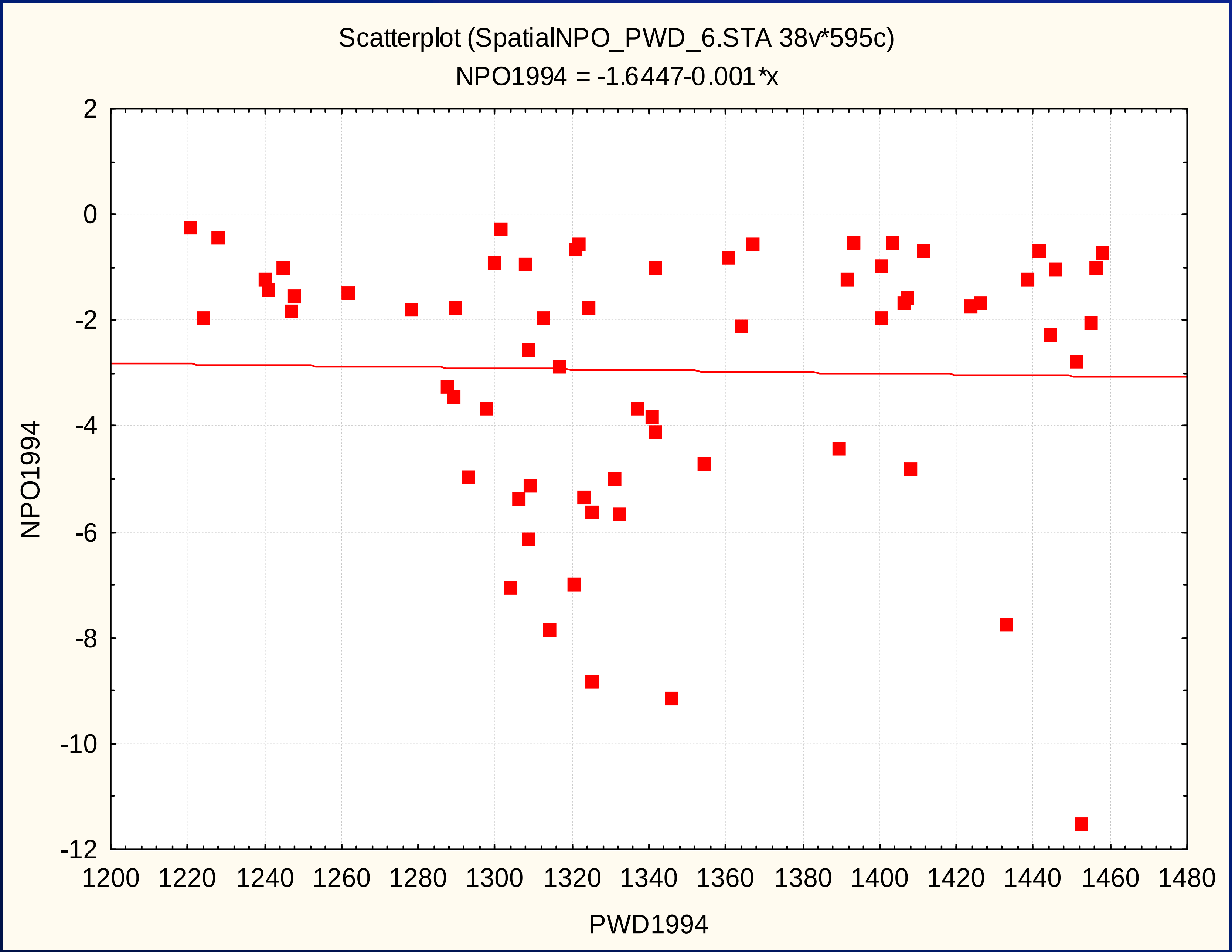

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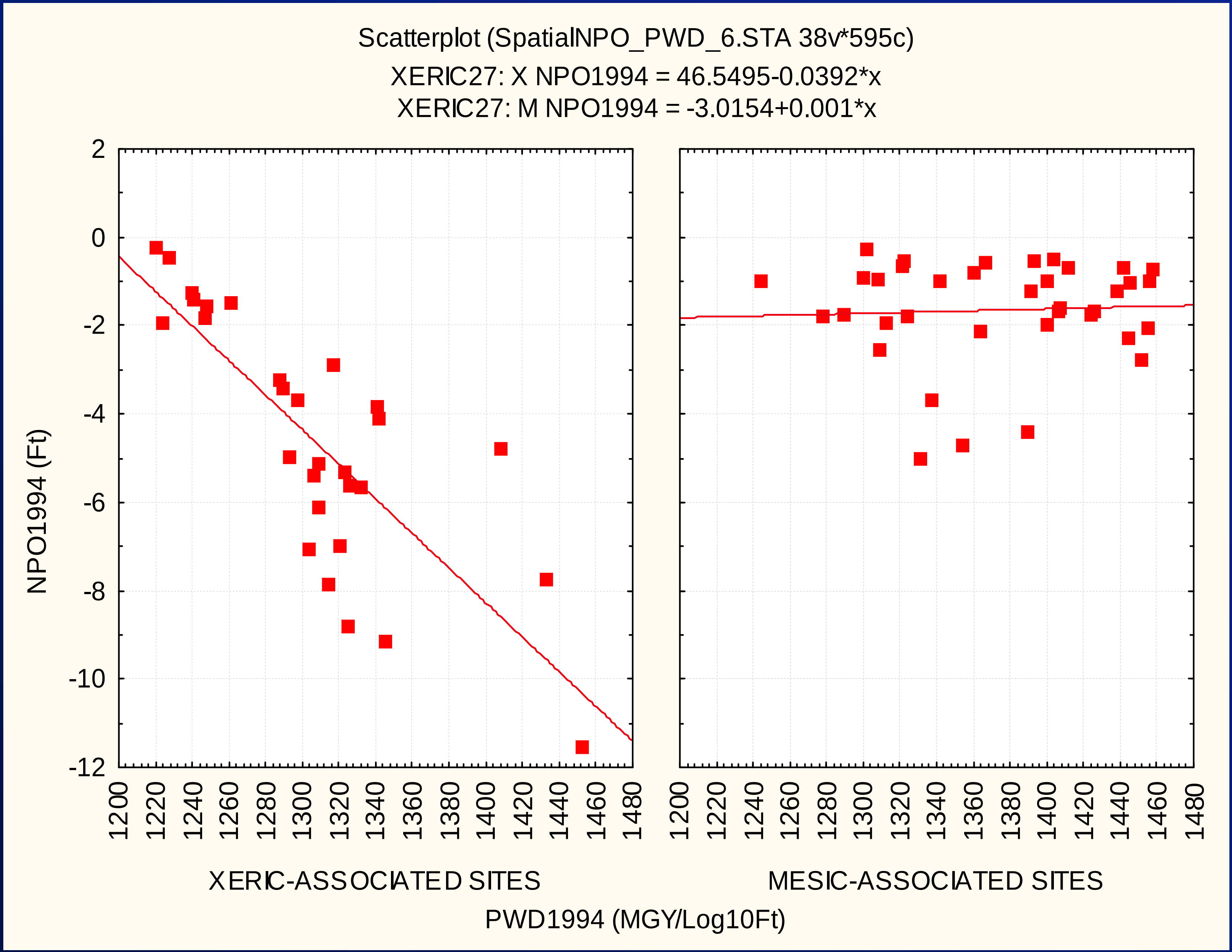

Xeric-associated Sites Results: WYs1990-2002

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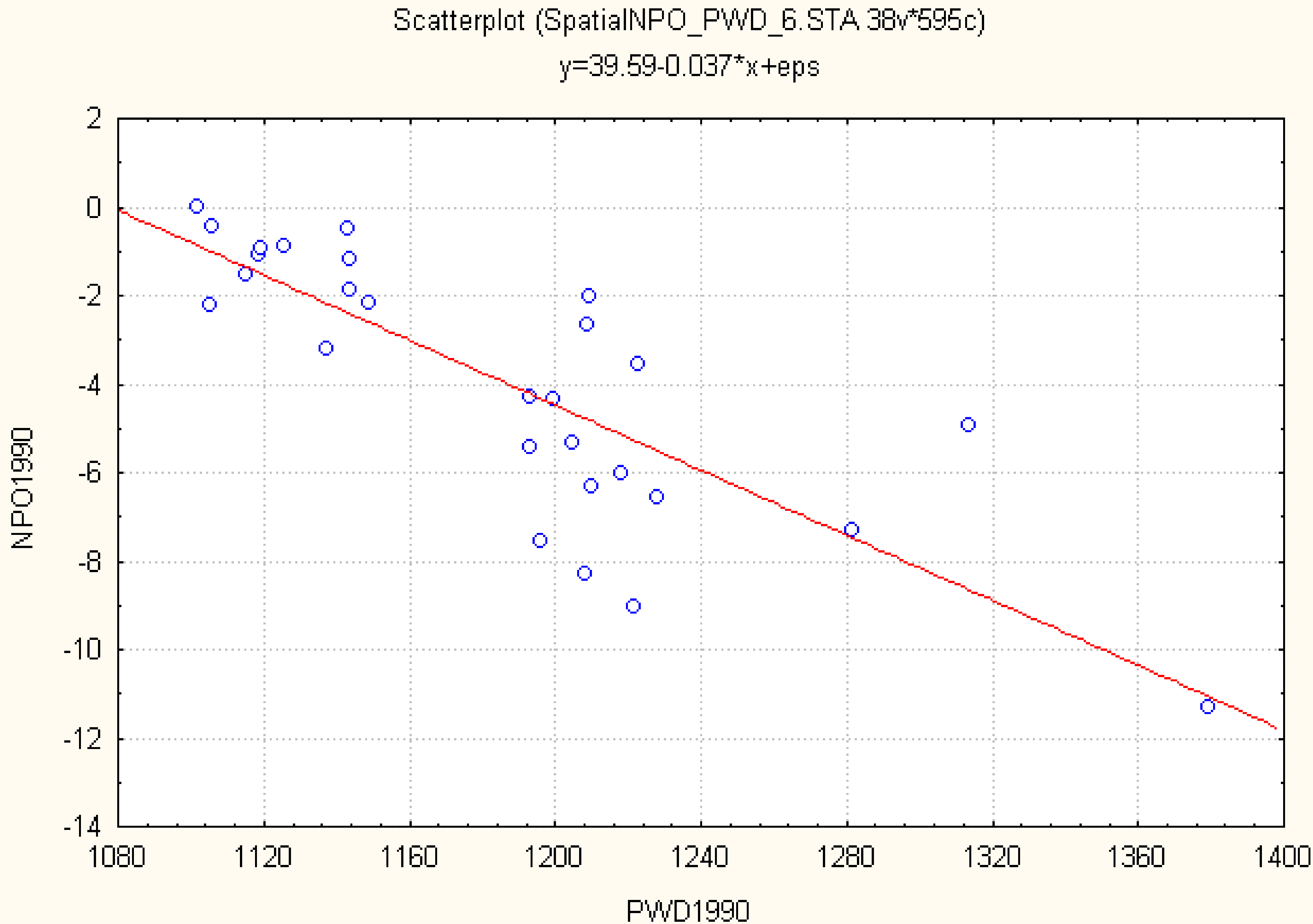

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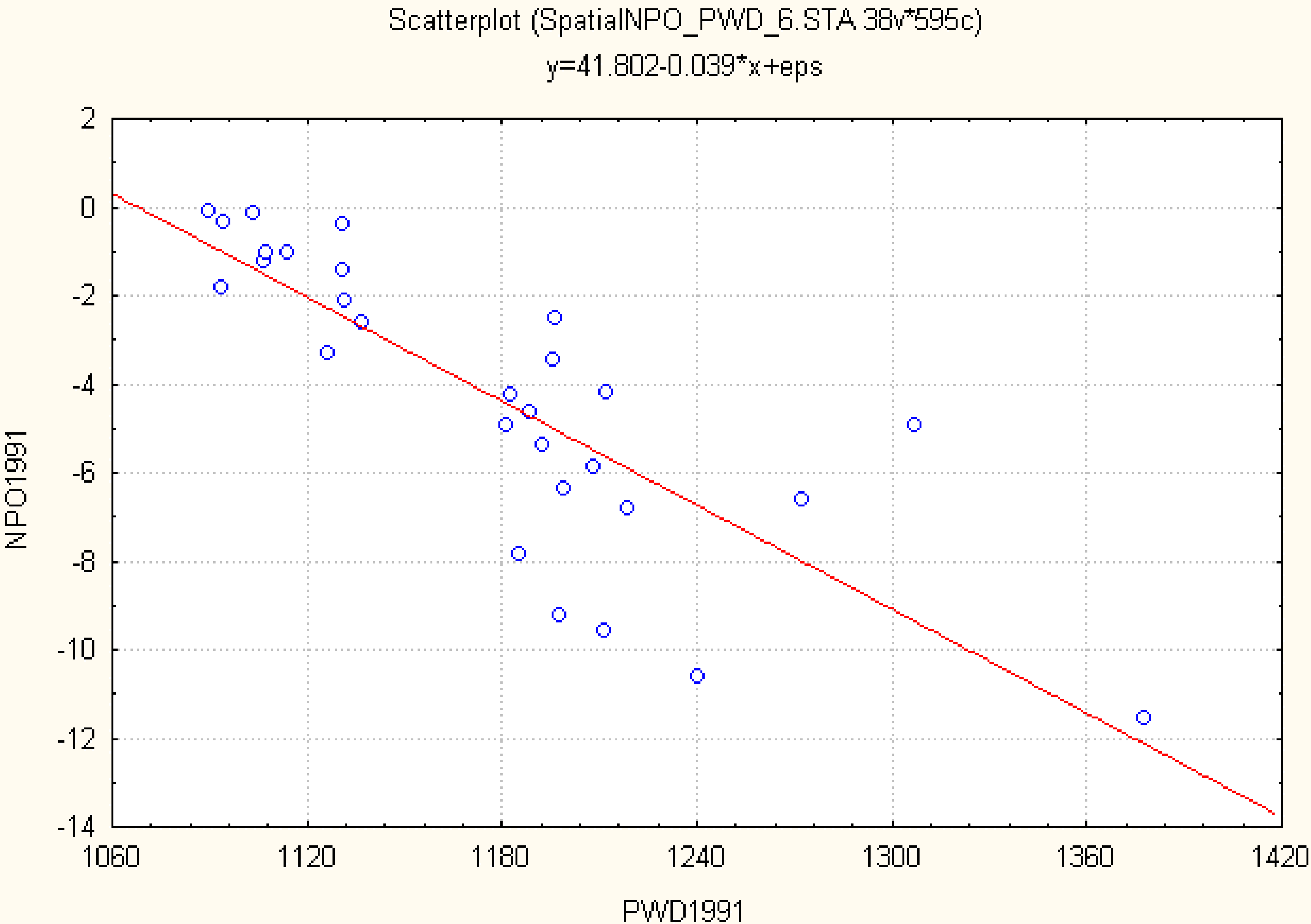

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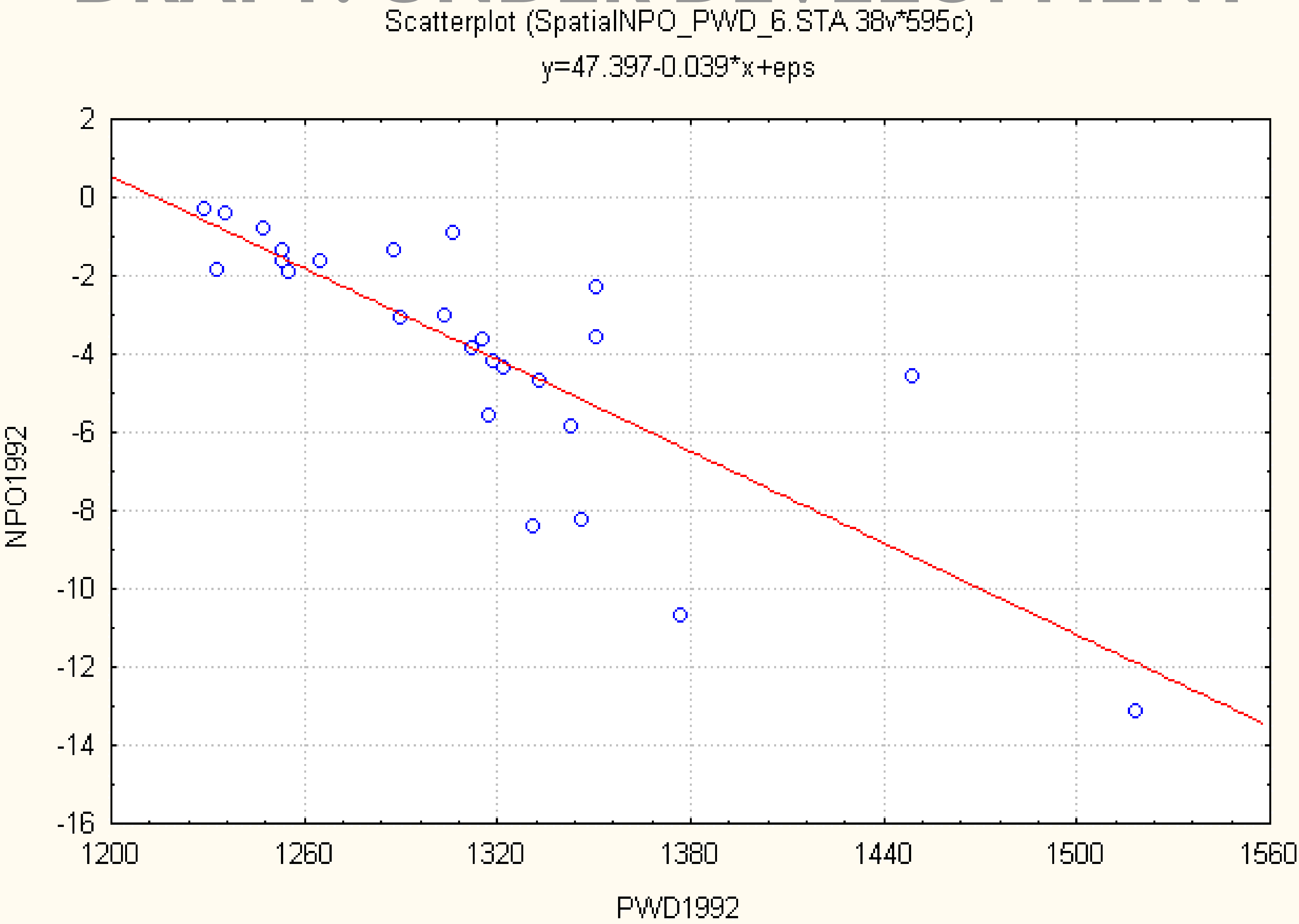

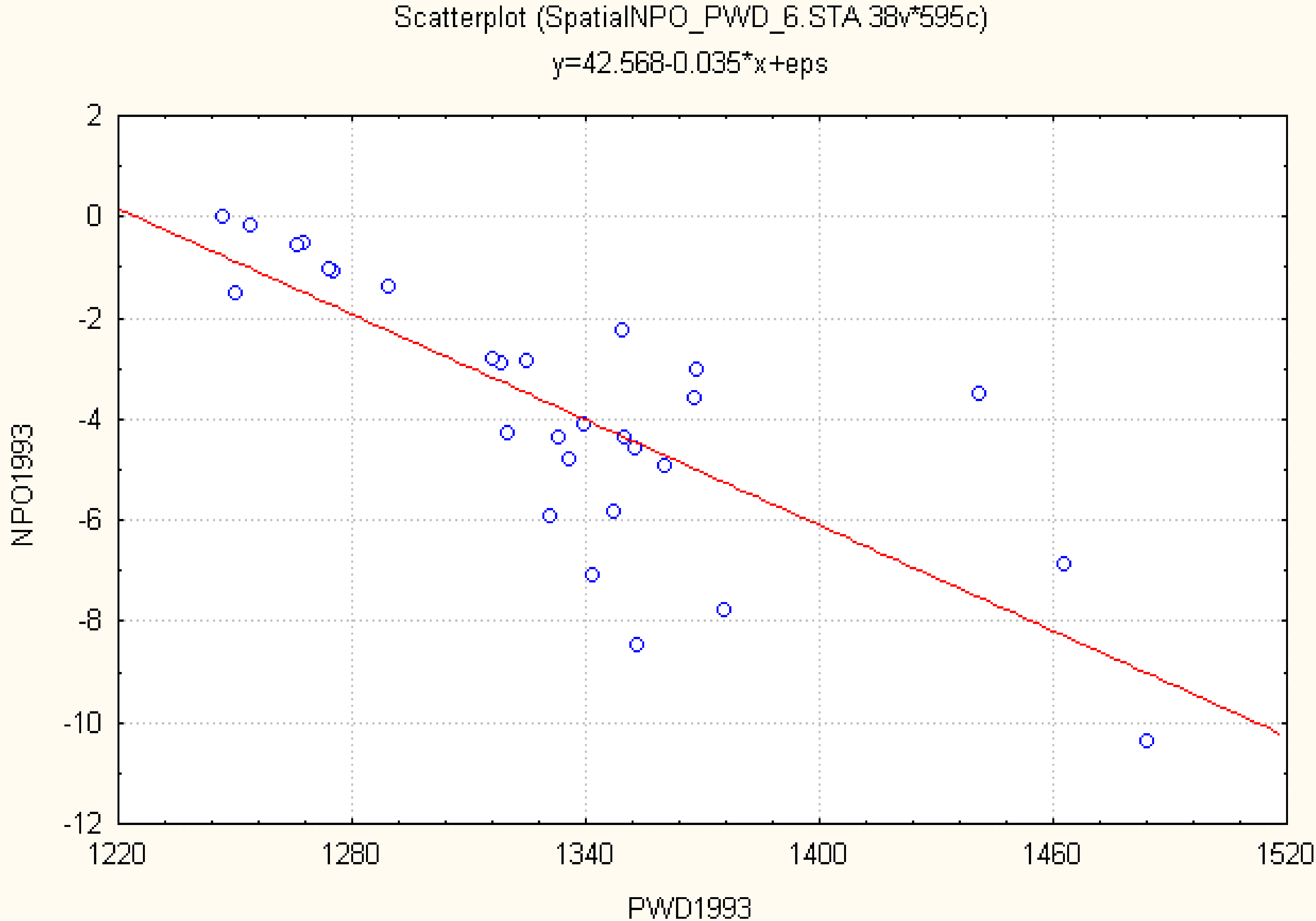
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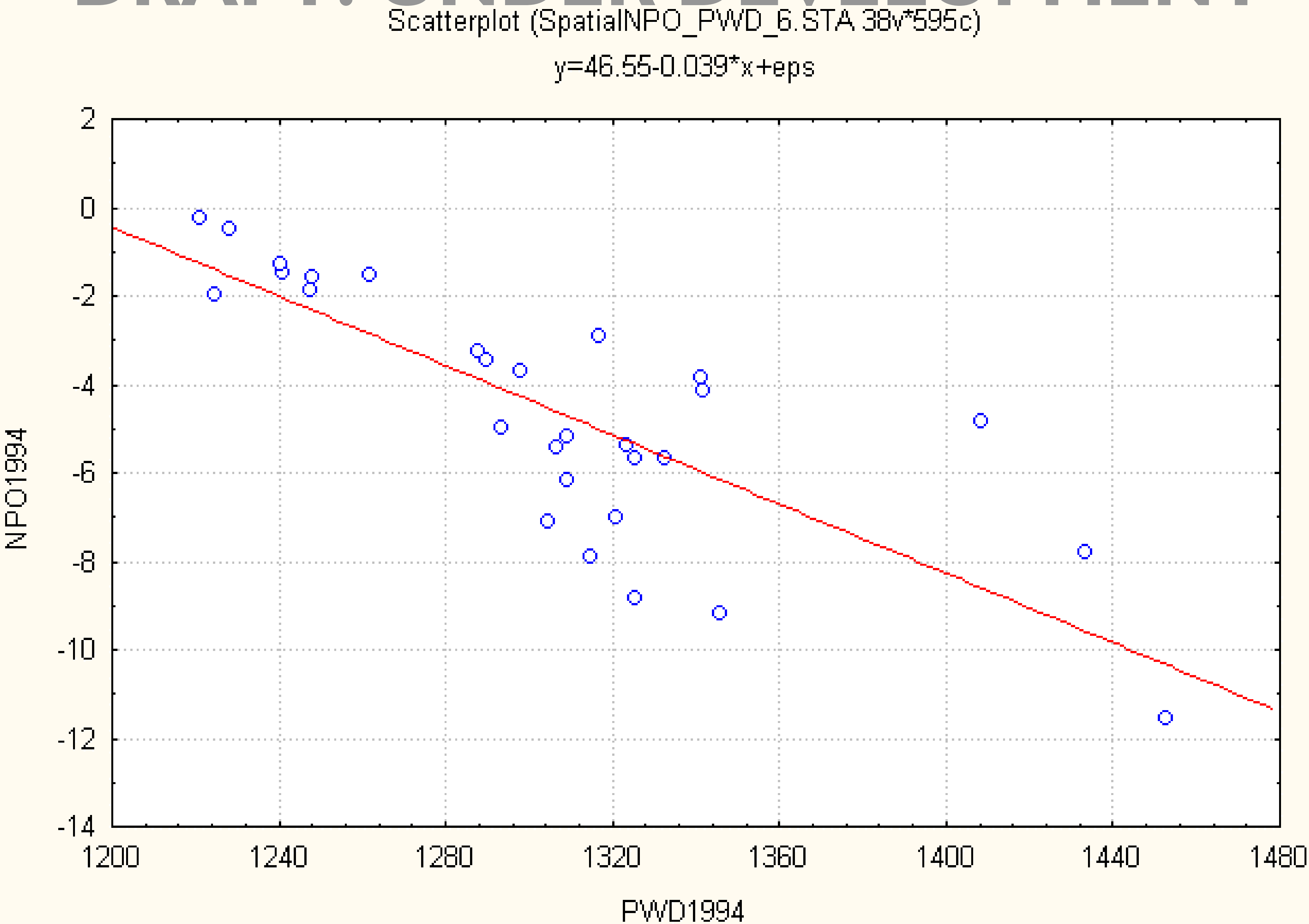
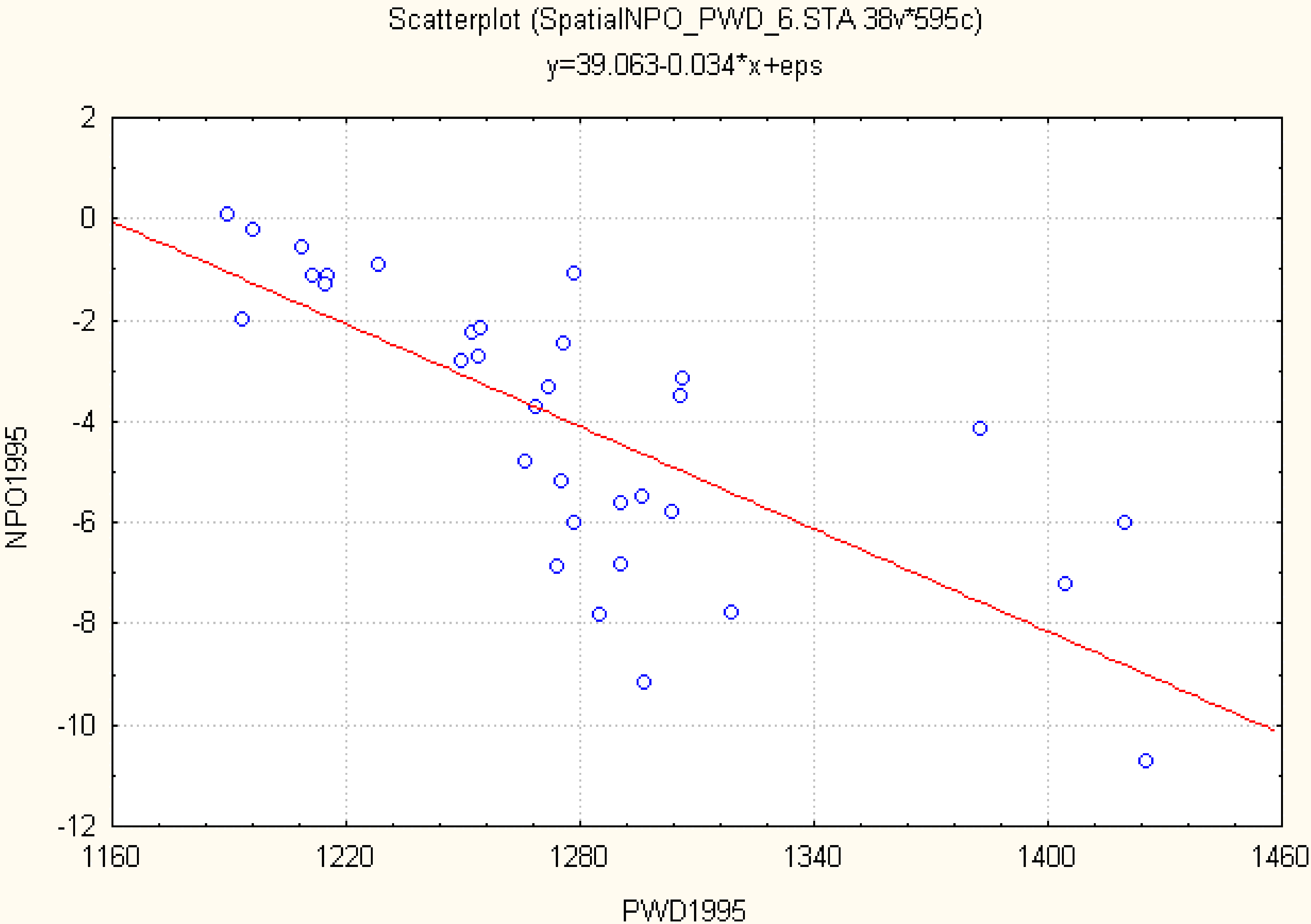
2
0
-2
-4
-6
-8
-10
-12
NPO1993
1220
1280
1340
1400
1460
1520
PWD1993


Scatterplot (SpatialNPO_PWD_6.STA 38v*595c)
y=46.55-0.039*x+eps
2
0
-2
-4
-6
-8
-10
-12
-14
NPO1994
1200
1240
1280
1320
1360
1400
1440
1480
PWD1994

DRAFT: UNDER DEVELOPMENT



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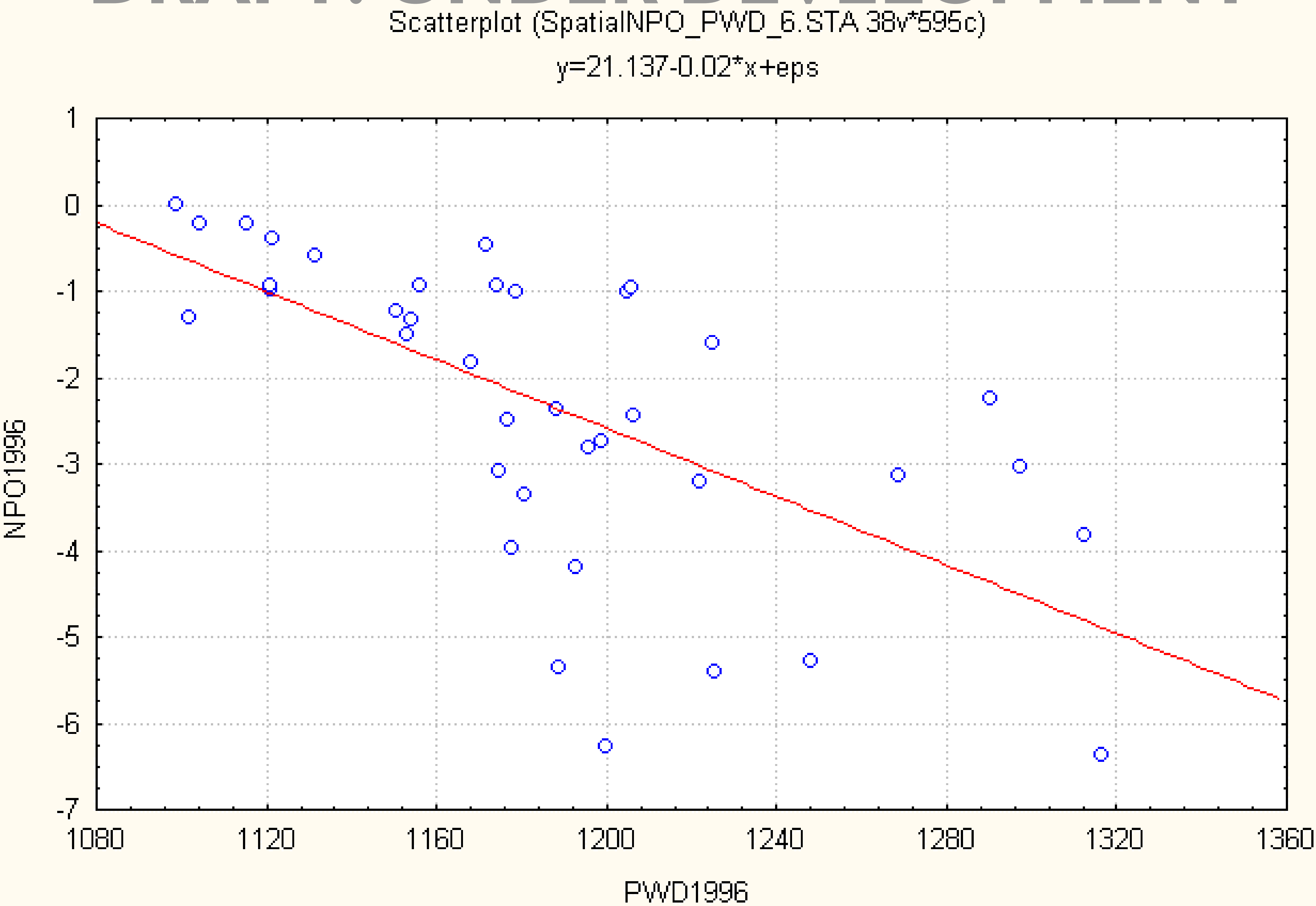

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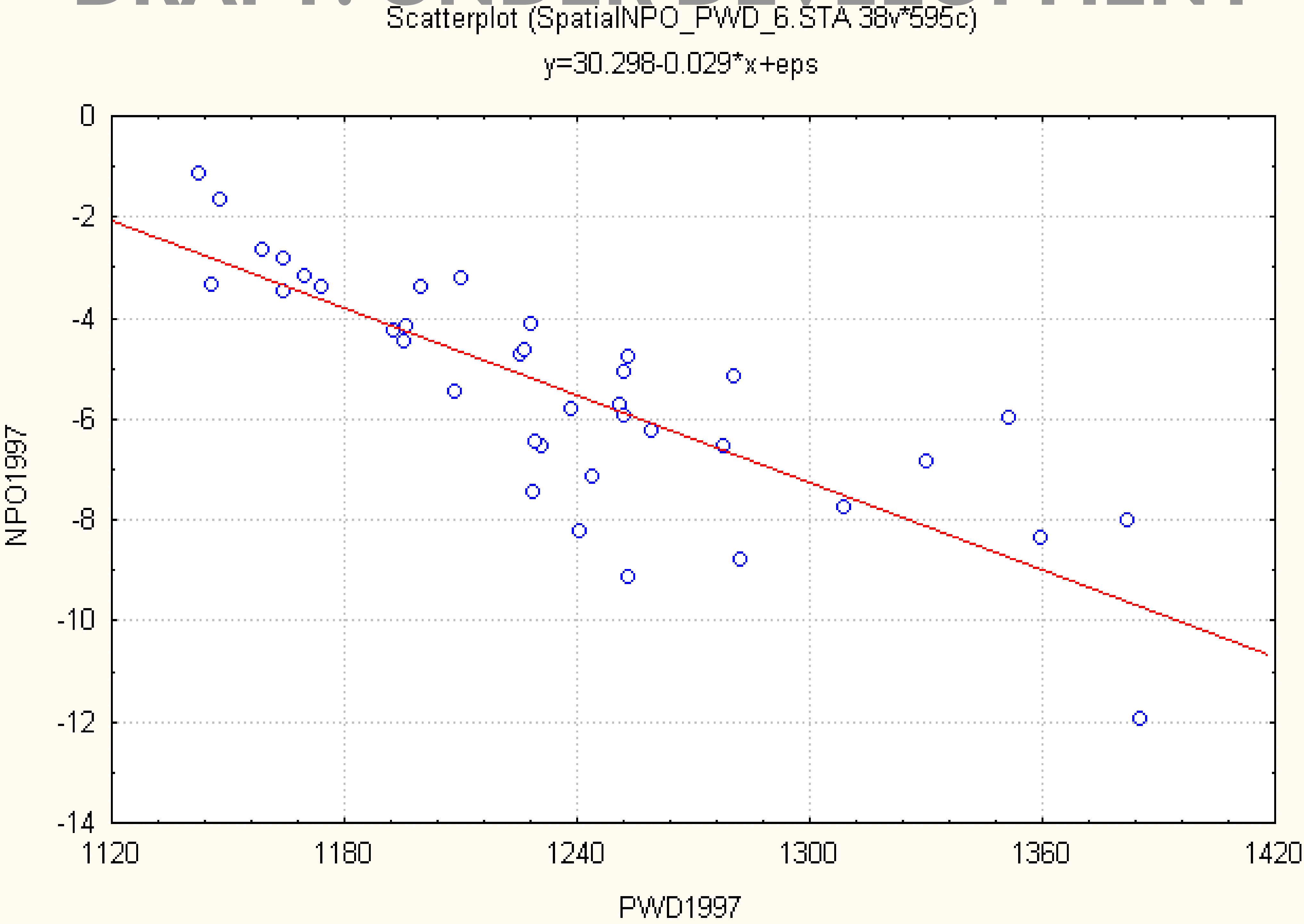

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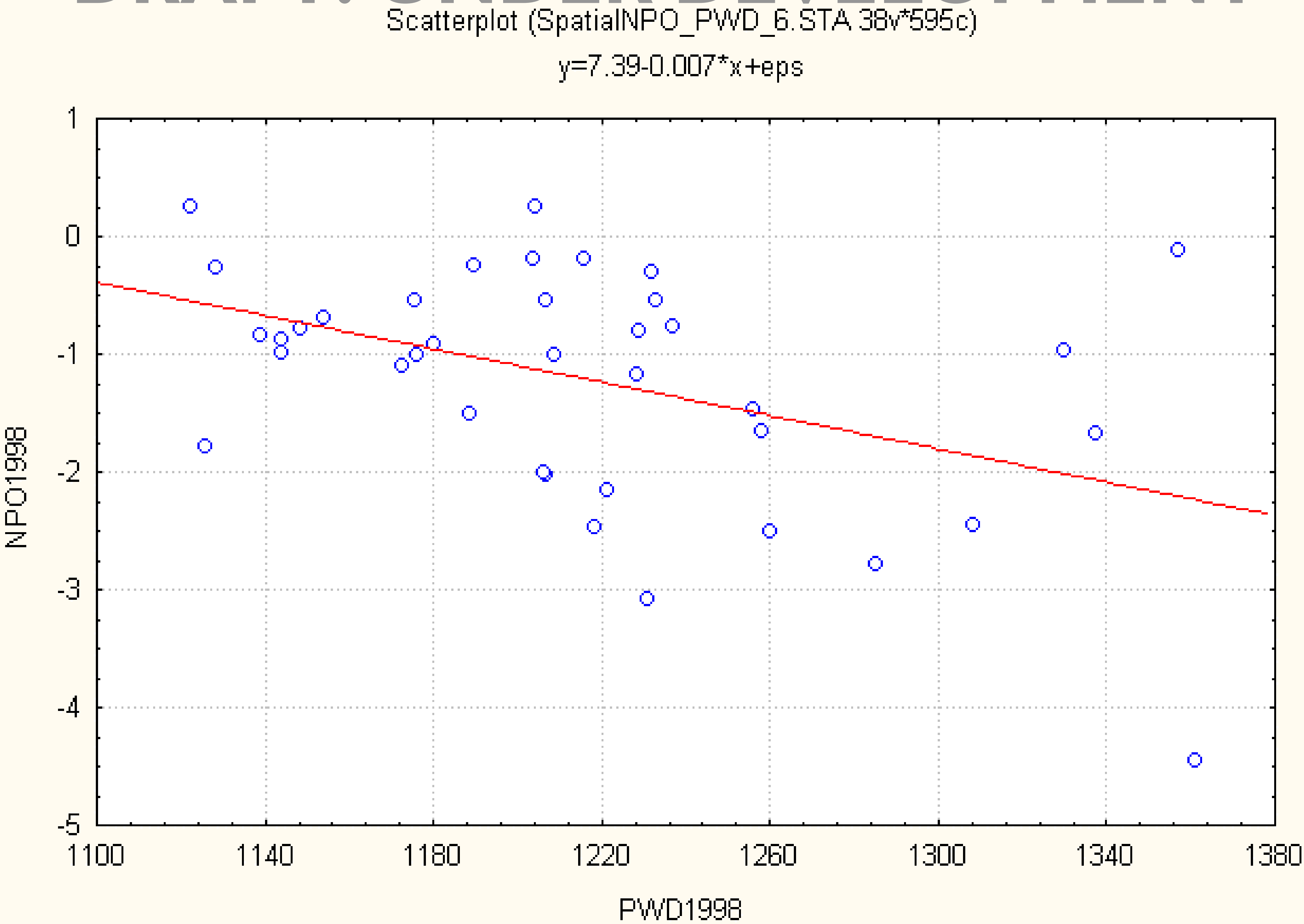

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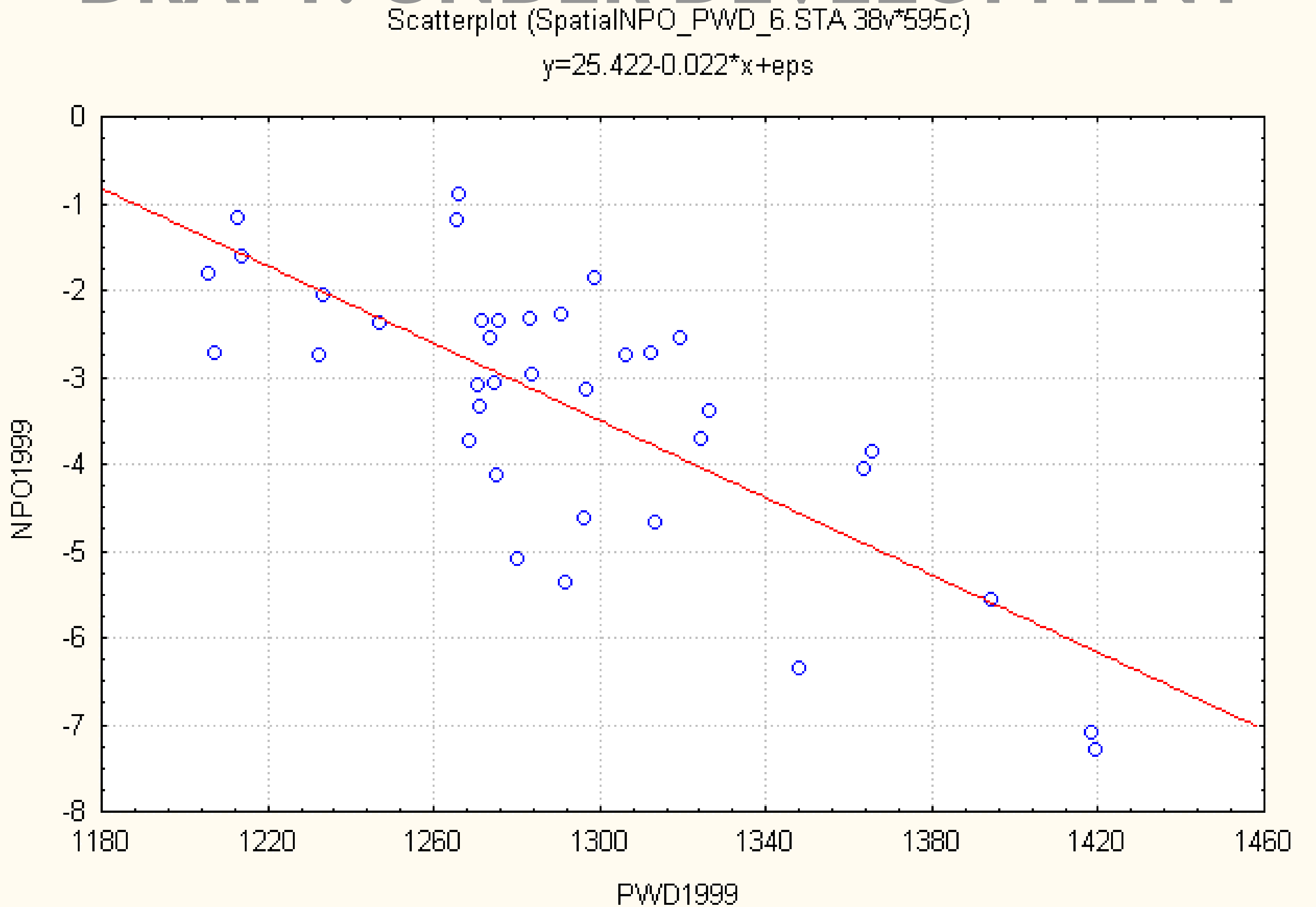

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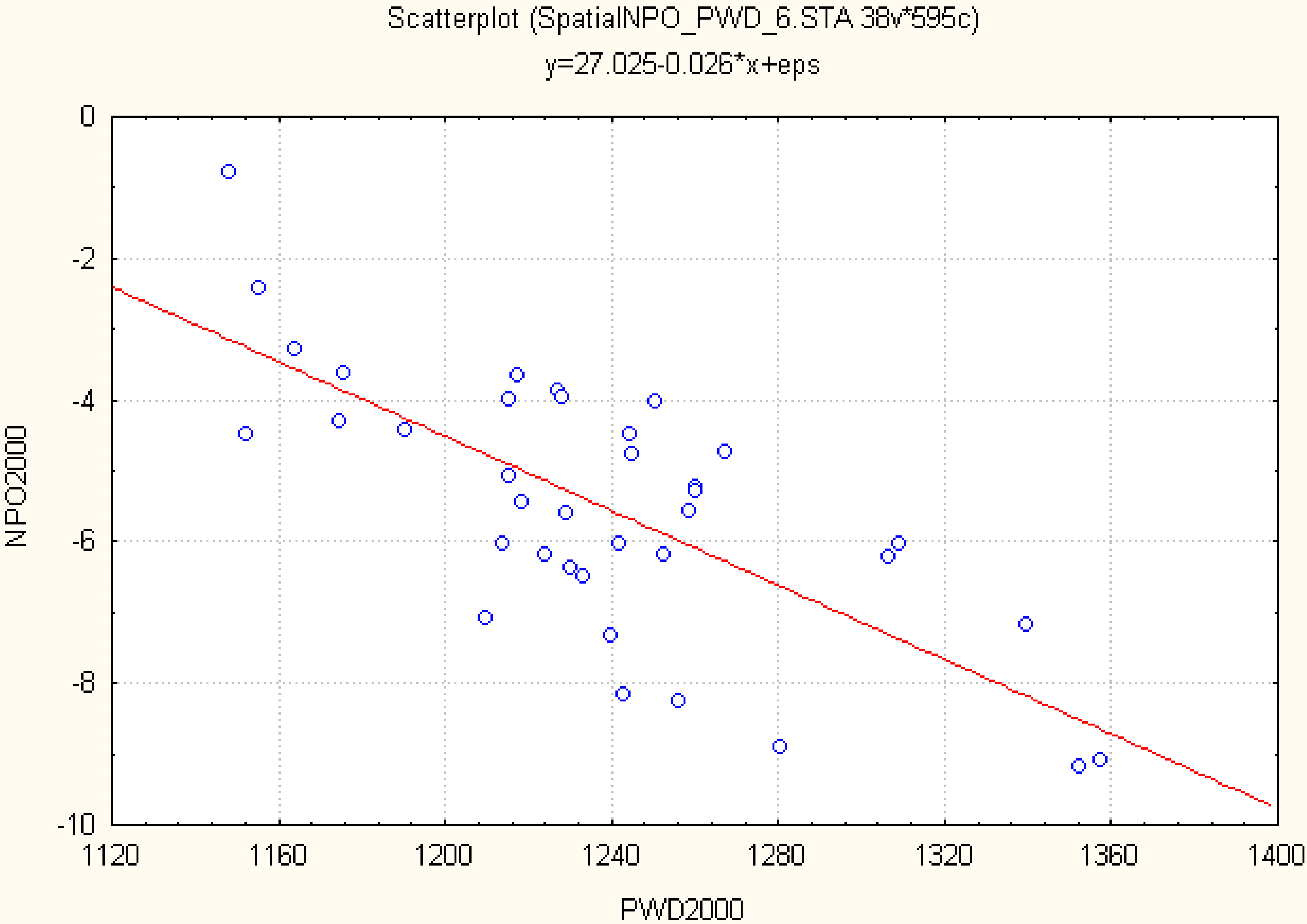
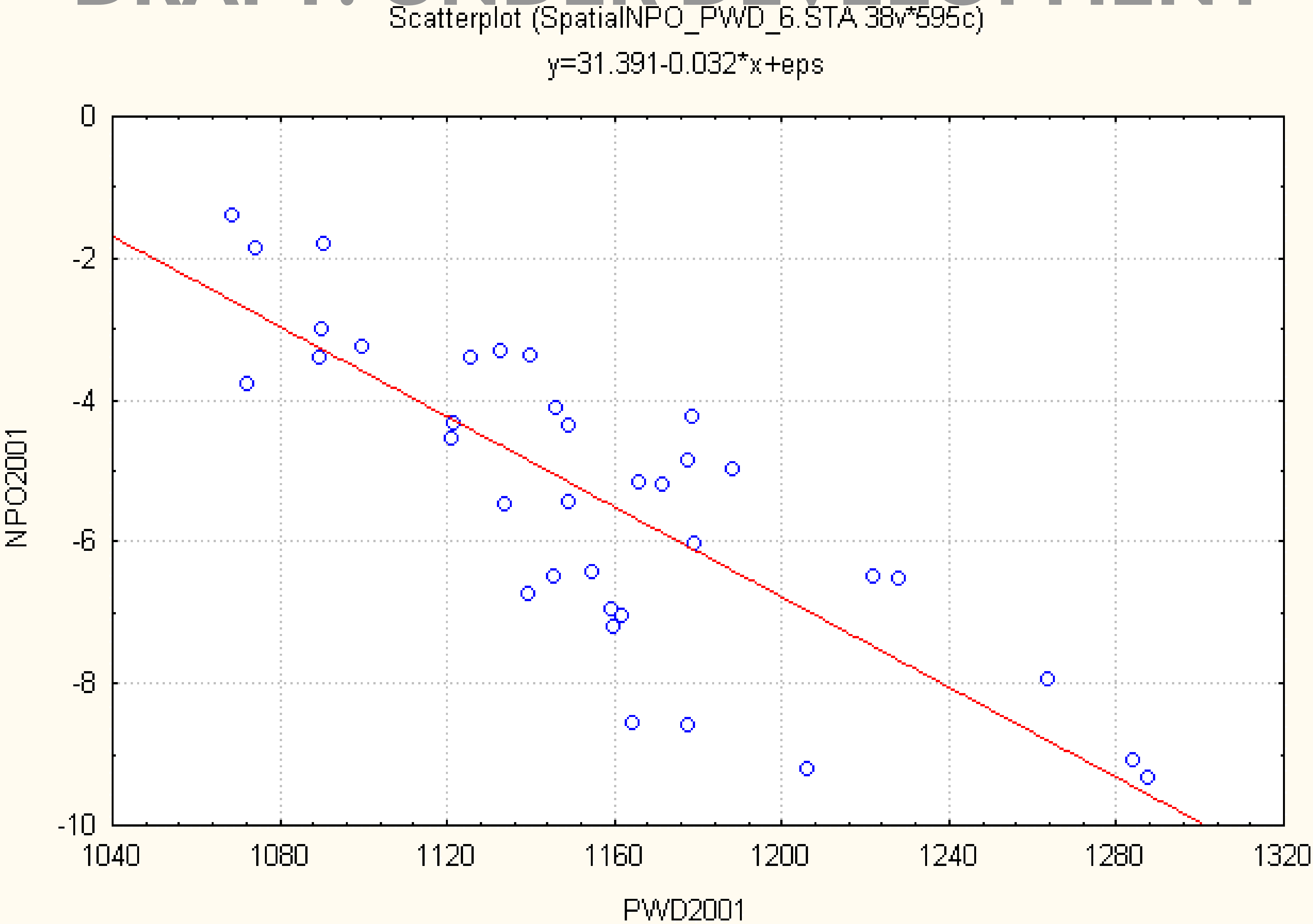


DRAFT: UNDER DEVELOPMENT



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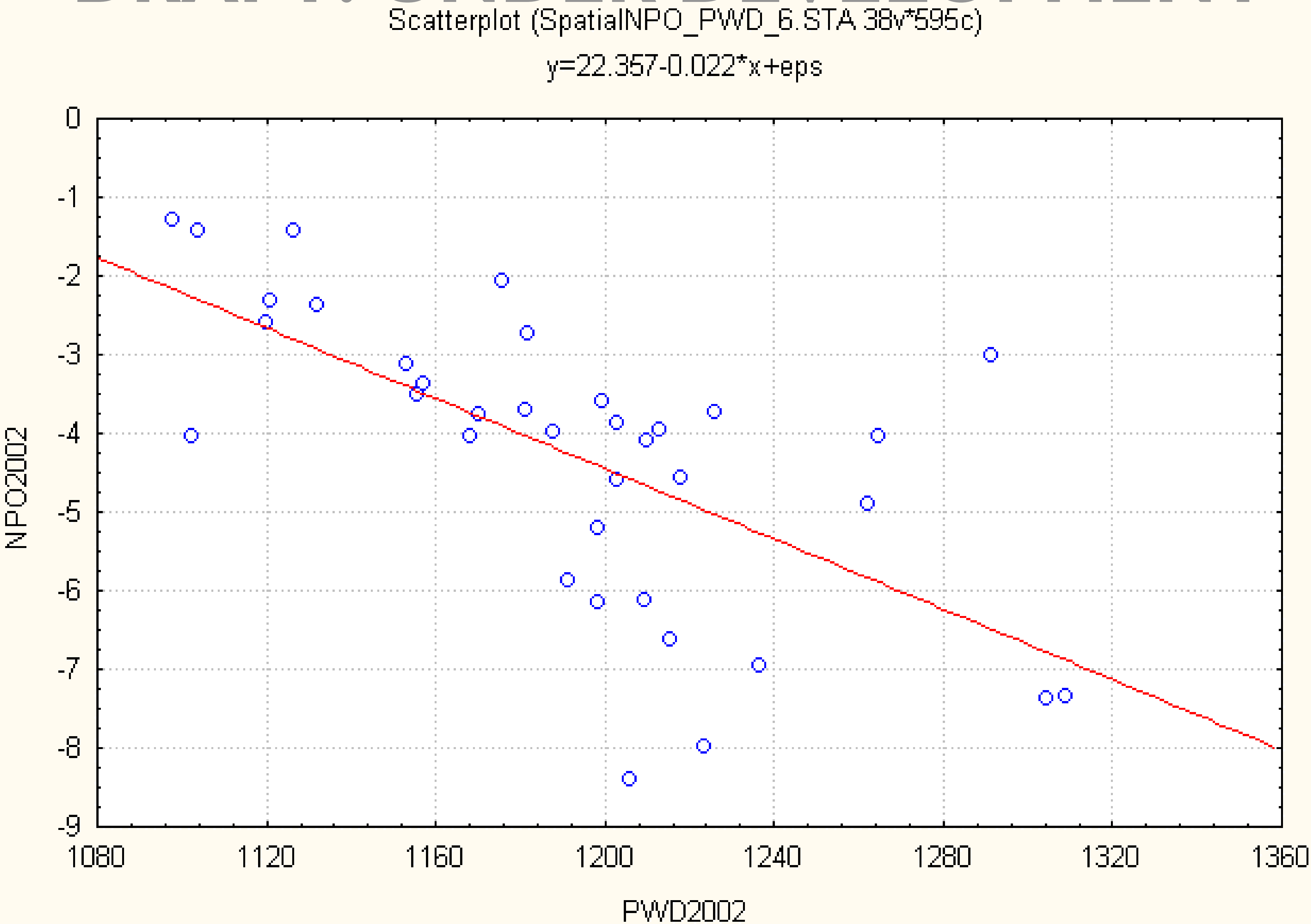

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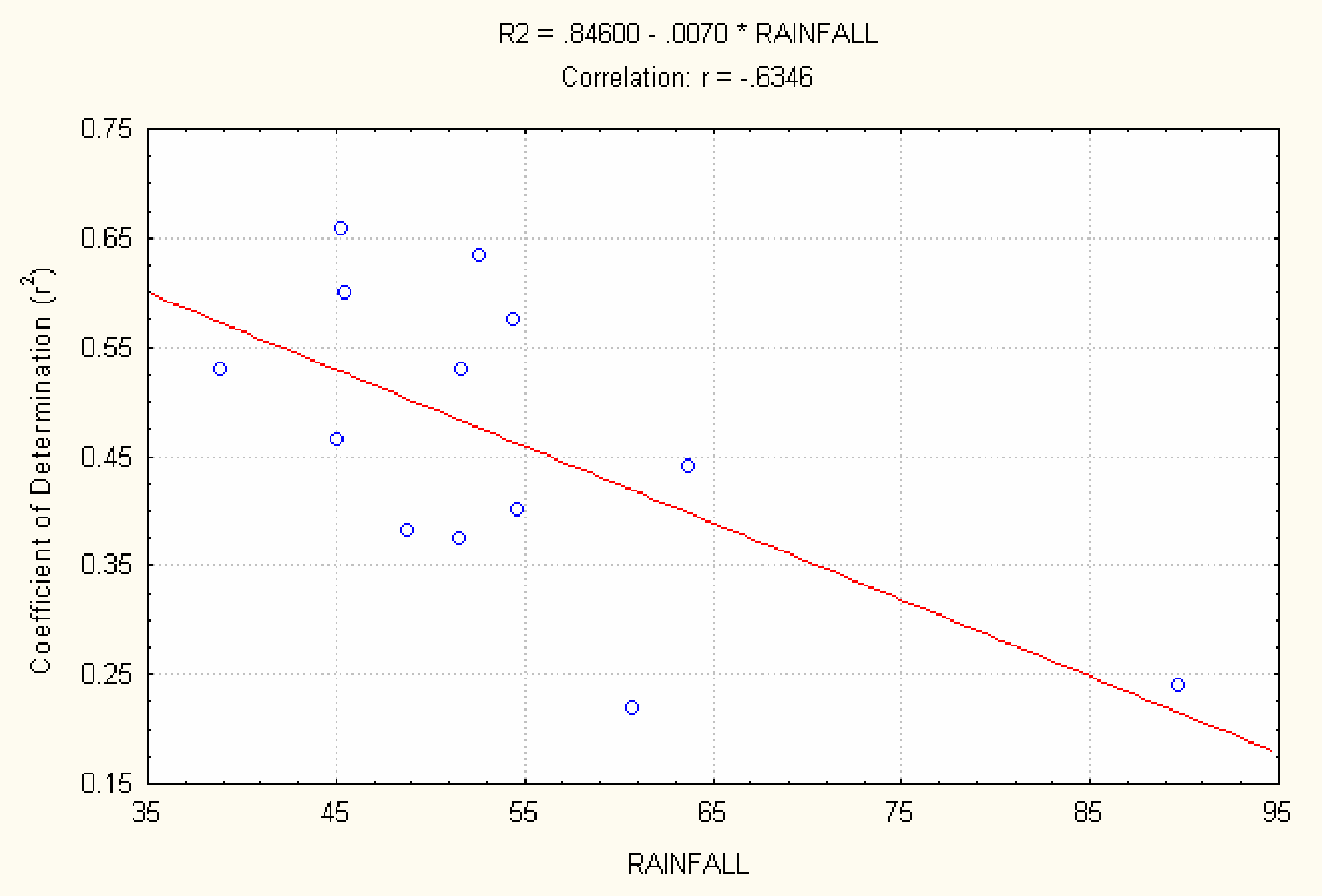
Regression Summary: Xeric-associated Sites

Water Year	No. sites (N)	Regression slope (B)	STD of B	r^2	P-Value
1990	27	-0.033	0.005	0.635	p<.00000
1991	31	-0.026	0.005	0.442	p<.00004
1992	29	-0.036	0.005	0.660	p<.00000
1993	29	-0.037	0.006	0.576	p<.00000
1994	32	-0.038	0.006	0.530	p<.00000
1995	37	-0.024	0.005	0.402	p<.00002
1996	35	-0.022	0.005	0.376	p<.00009
1997	37	-0.041	0.006	0.600	p<.00000
1998	36	-0.008	0.003	0.241	p<.00237
1999	36	-0.025	0.004	0.530	p<.00000
2000	36	-0.029	0.005	0.466	p<.00000
2001	35	-0.021	0.004	0.382	p<.00008
2002	36	-0.018	0.006	0.221	p<.00380

Significant p-values are shaded in gray.

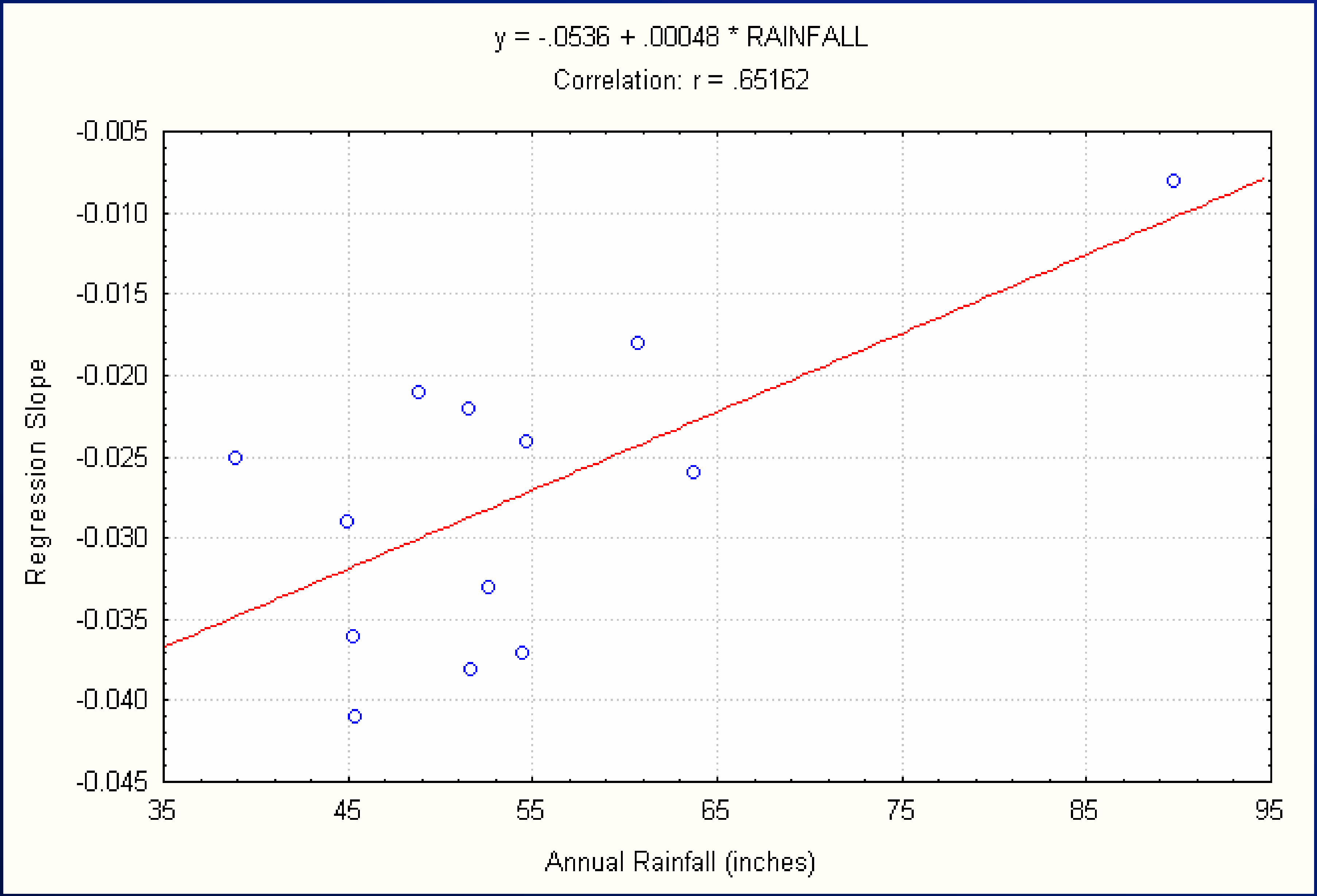
DRAFT: UNDER DEVELOPMENT

r^2/Rainfall Relationship (Xeric-associated)



DRAFT: UNDER DEVELOPMENT

Slope/Rainfall Relationship (Xeric-associated)



Mesic-associated Sites Results: WYs 1990-2002

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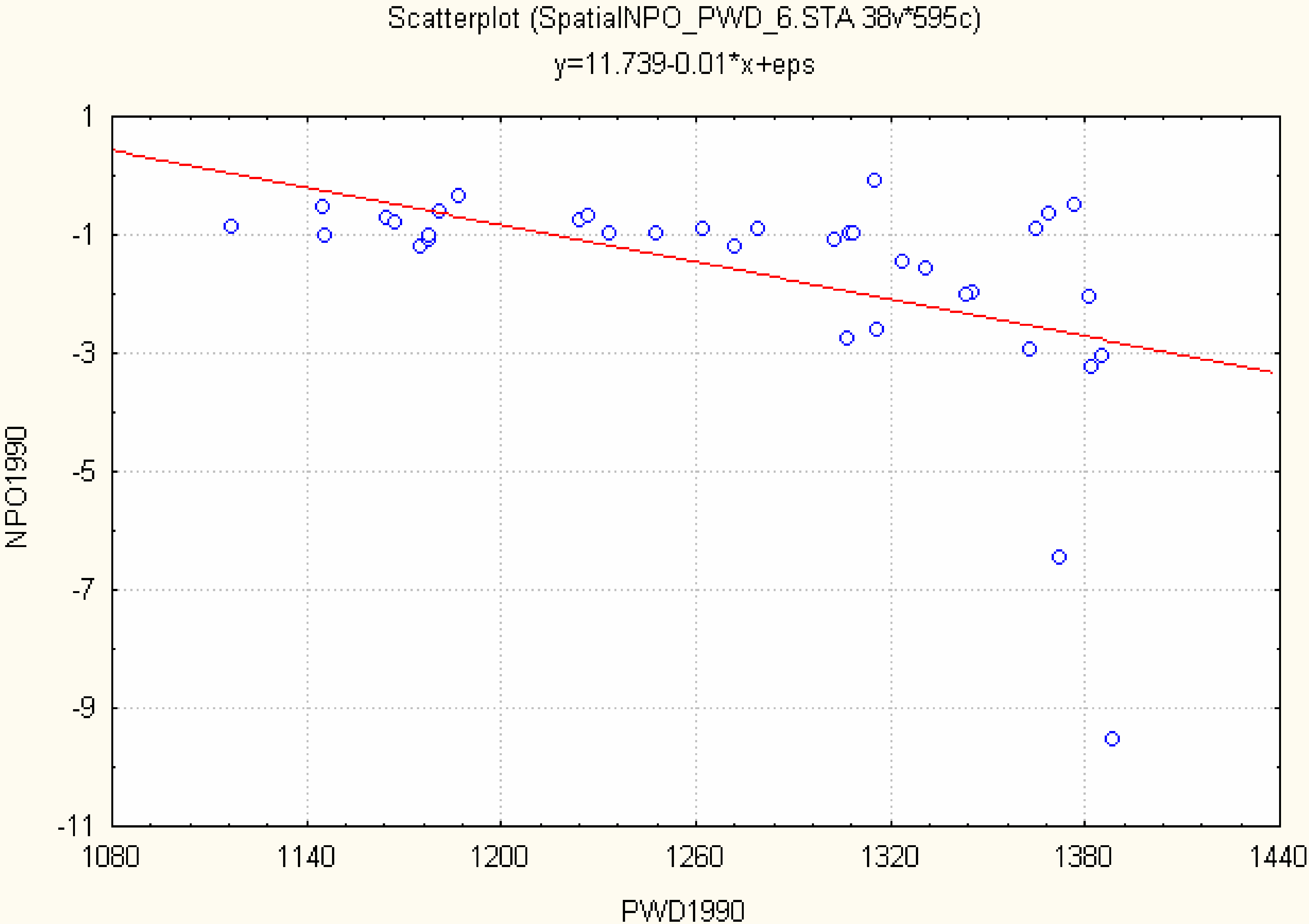

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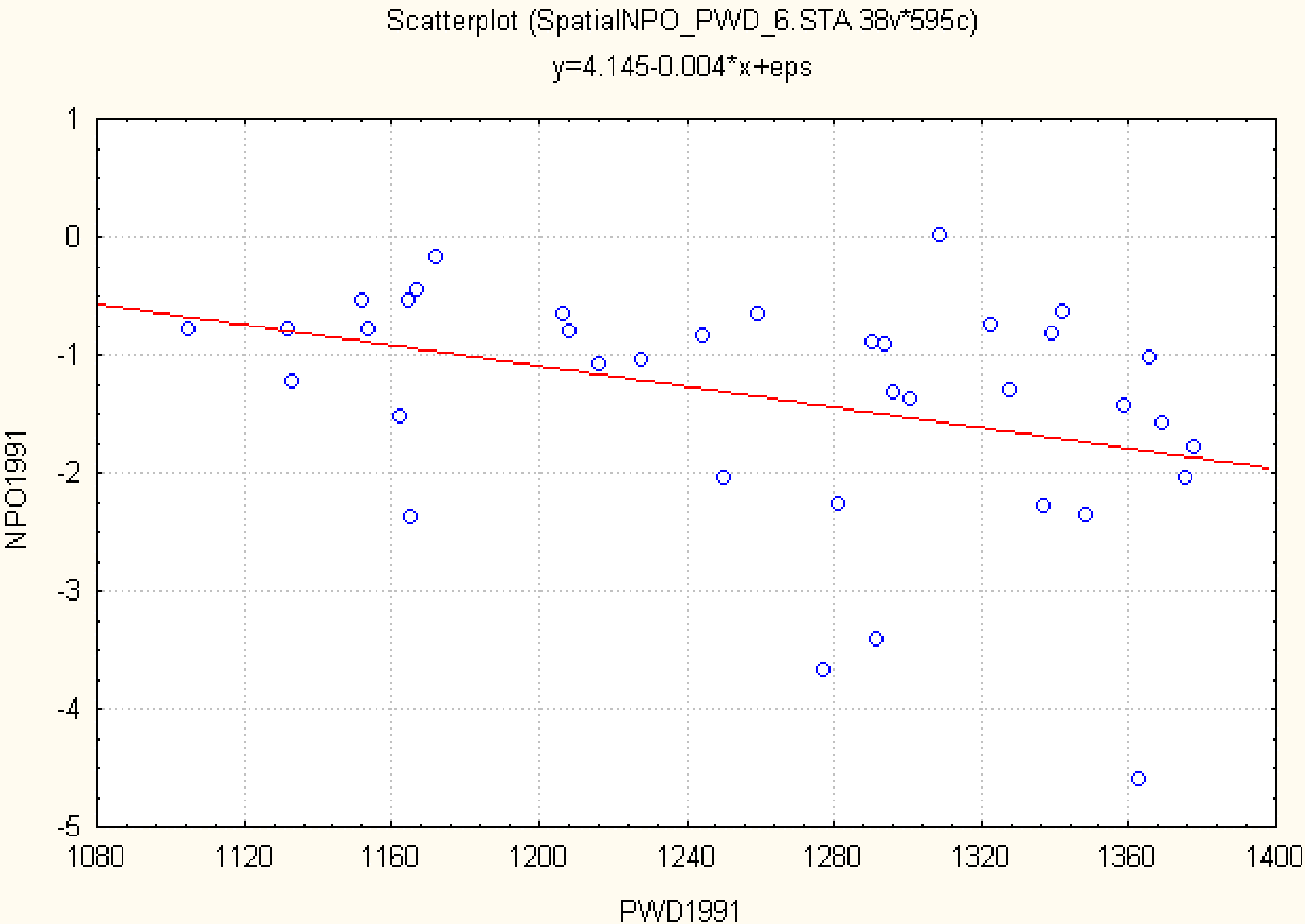
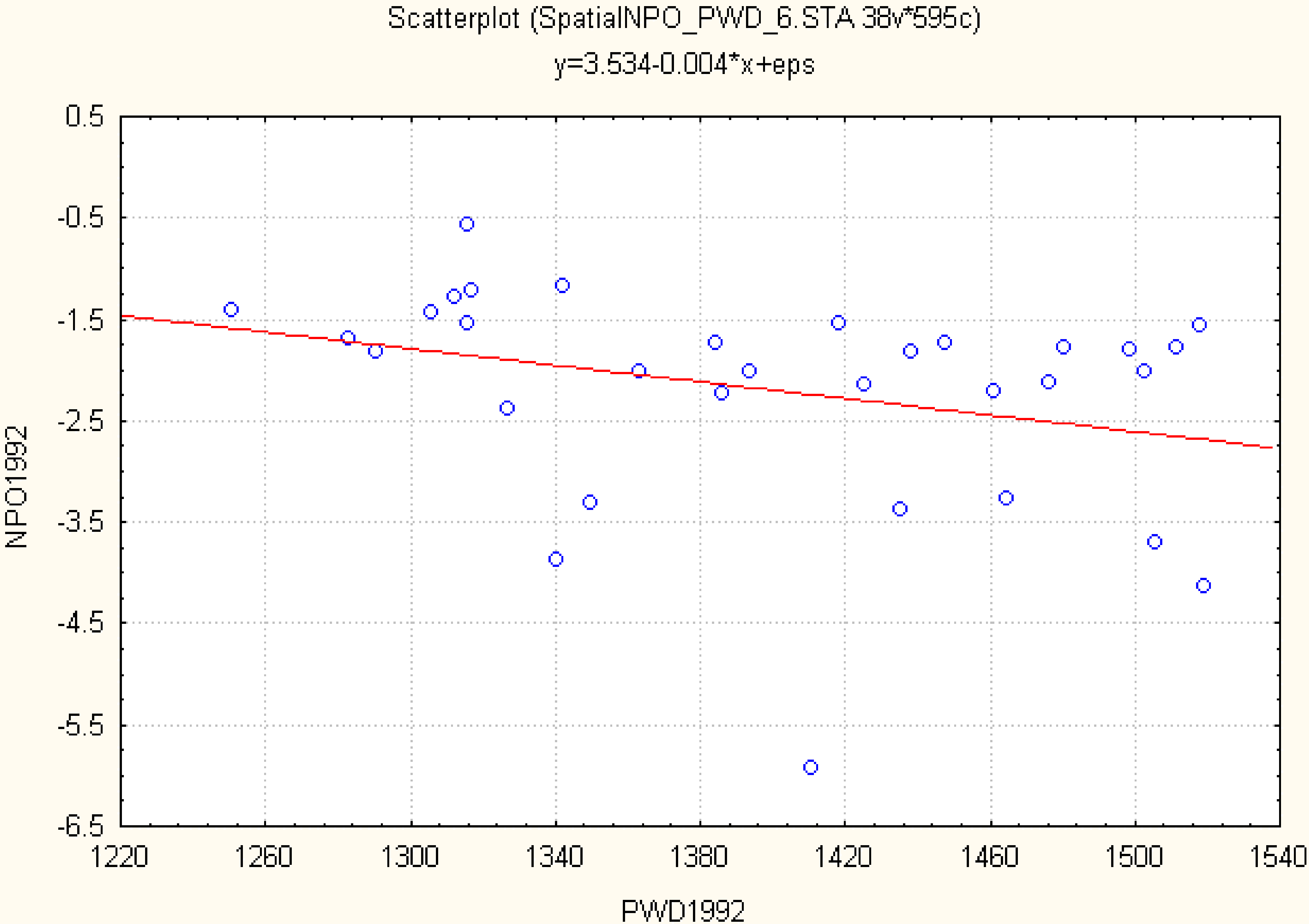
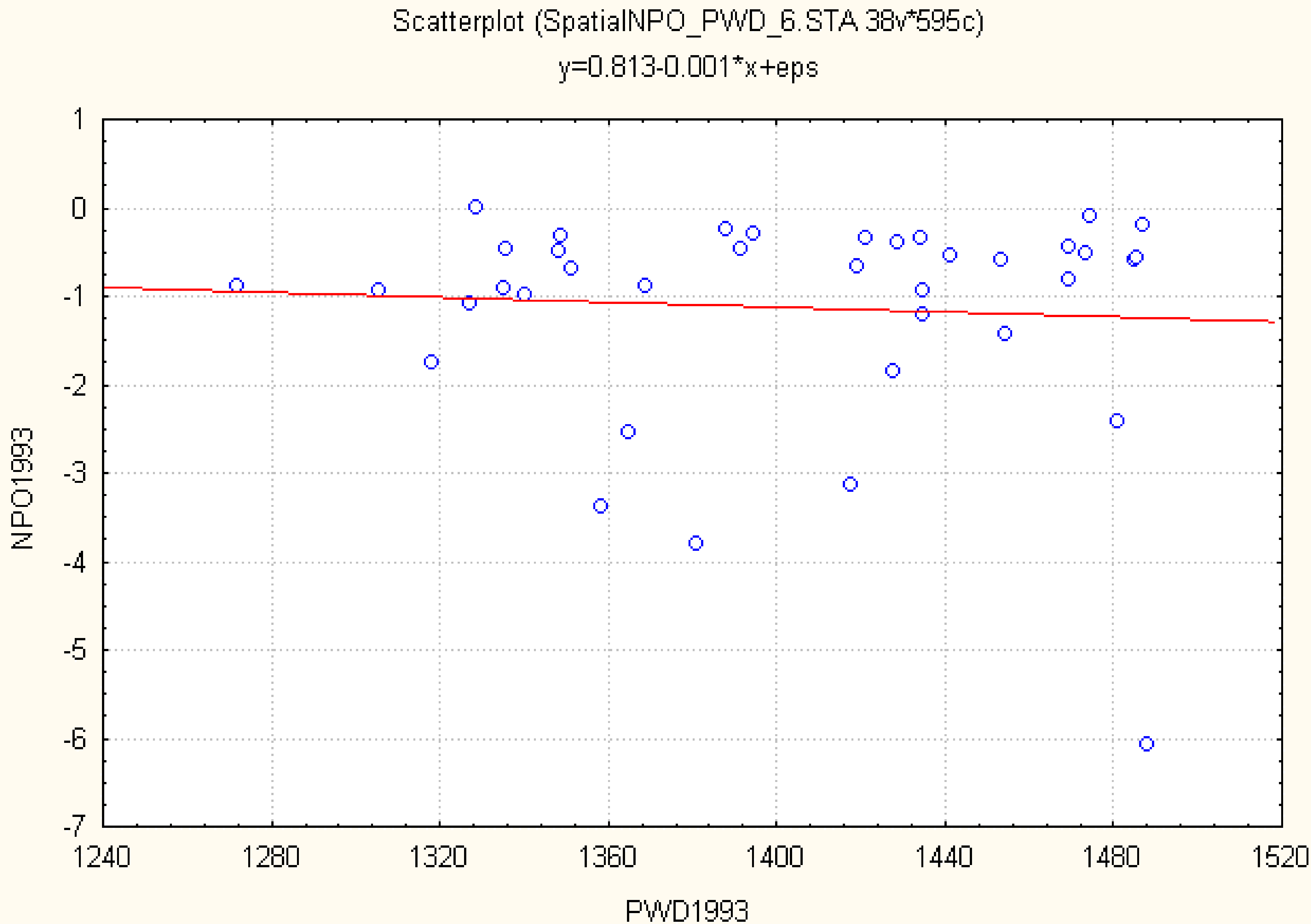
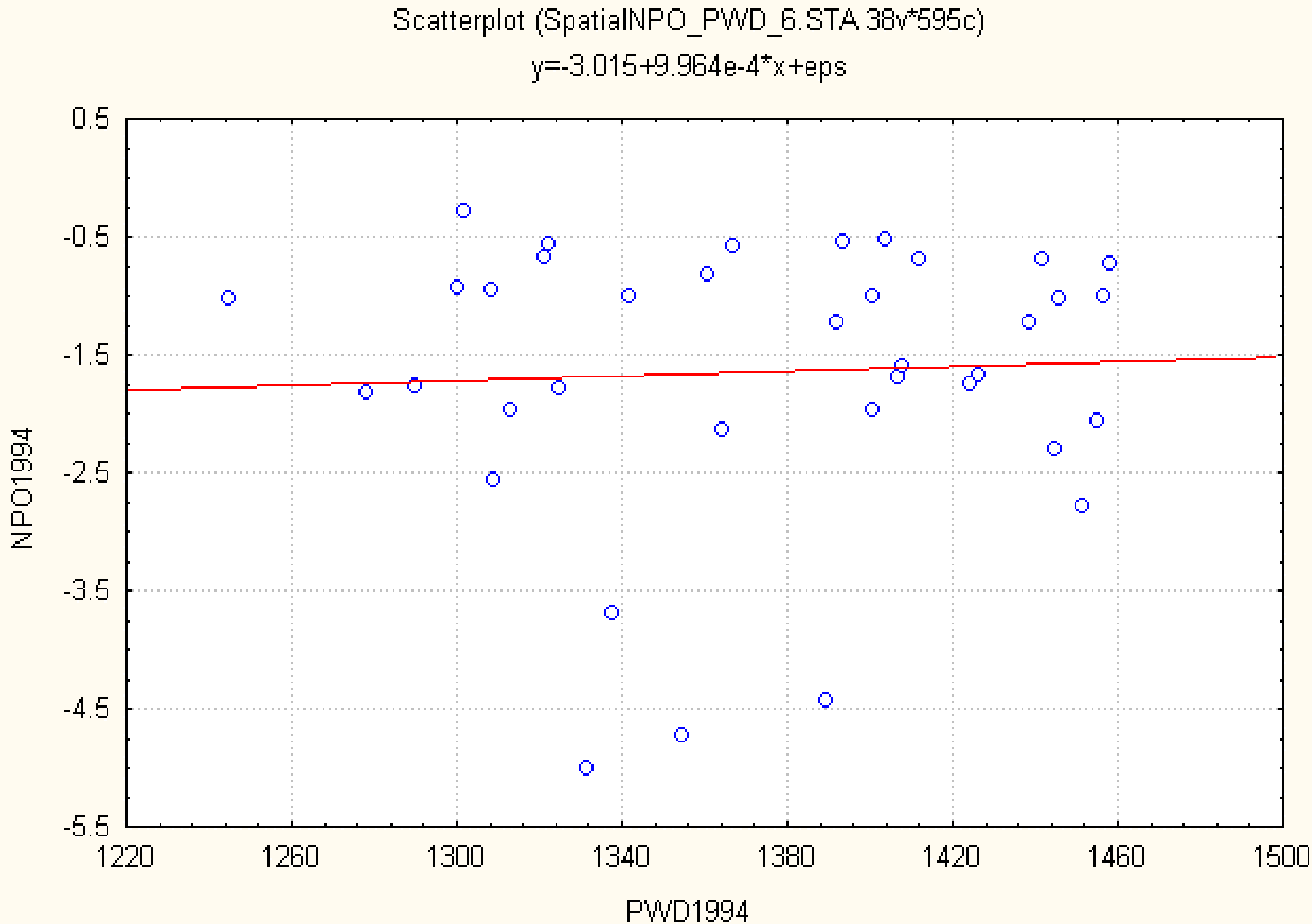



Scatterplot (SpatialNPO_PWD_6.STA 38v*595c)
y=3.534-0.004*x+eps
0.5
-0.5
-1.5
-2.5
-3.5
-4.5
-5.5
-6.5
NPO1992
1220
1260
1300
1340
1380
1420
1460
1500
1540
PWD1992

DRAFT: UNDER DEVELOPMENT



DRAFT: UNDER DEVELOPMENT



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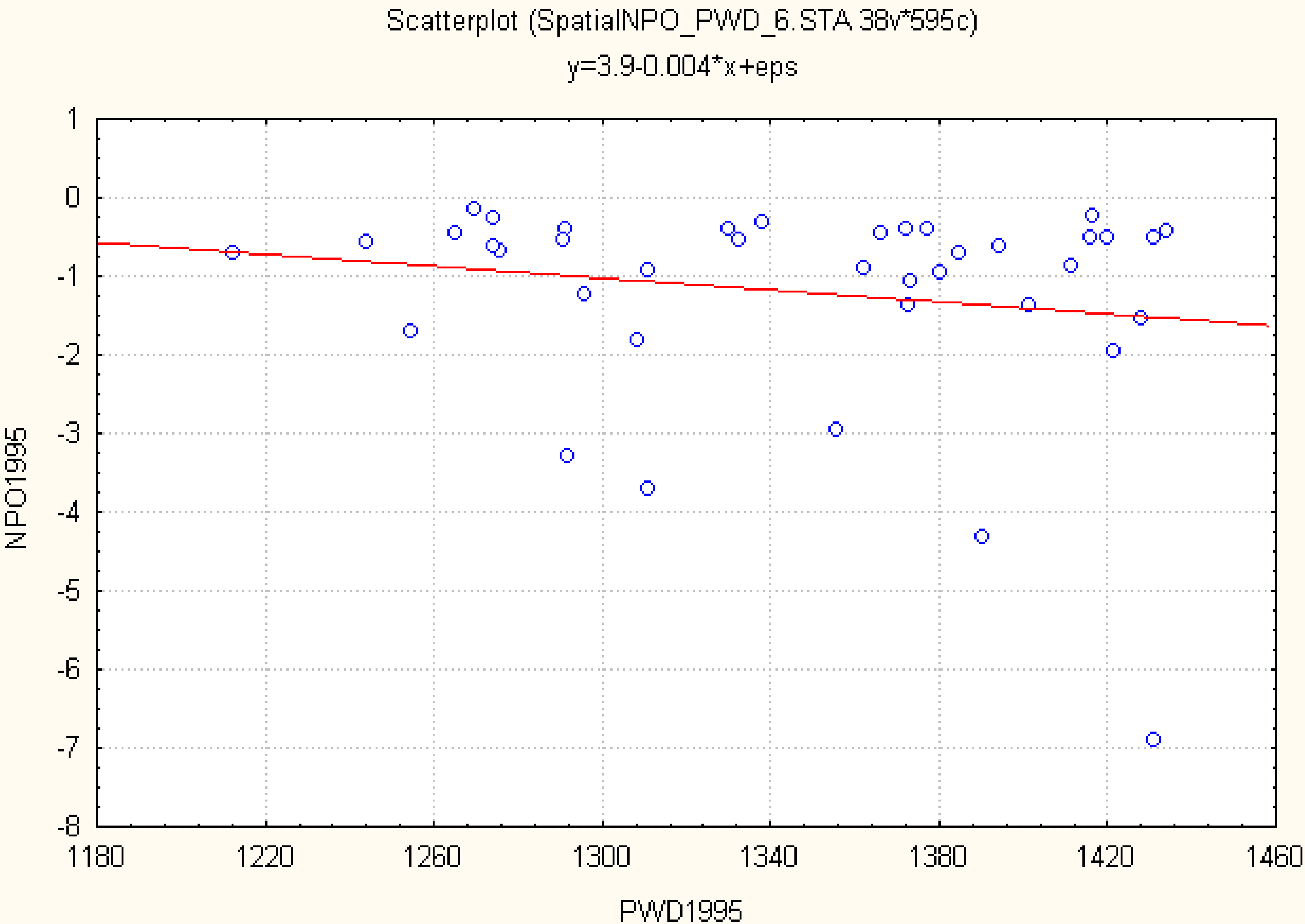

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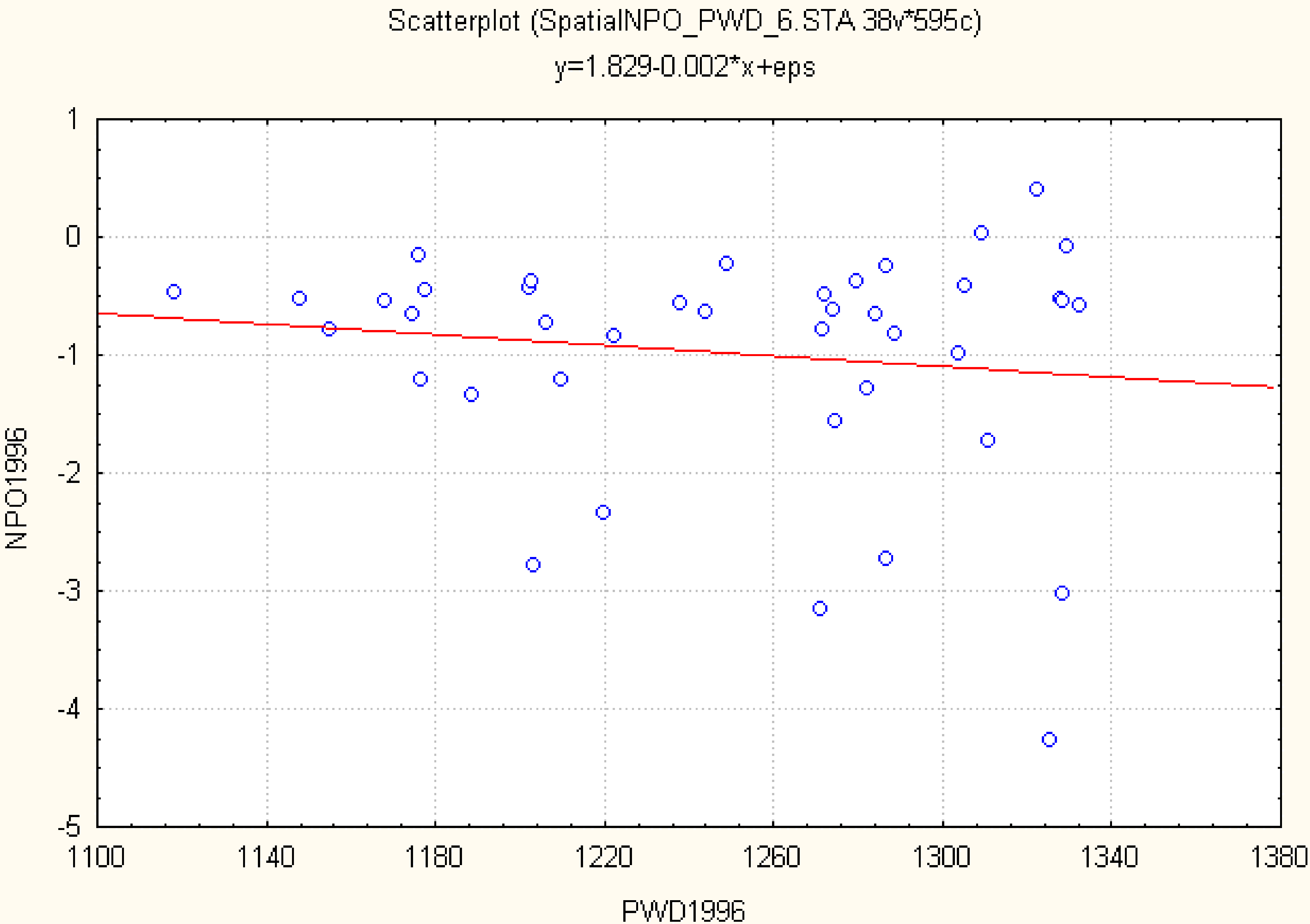
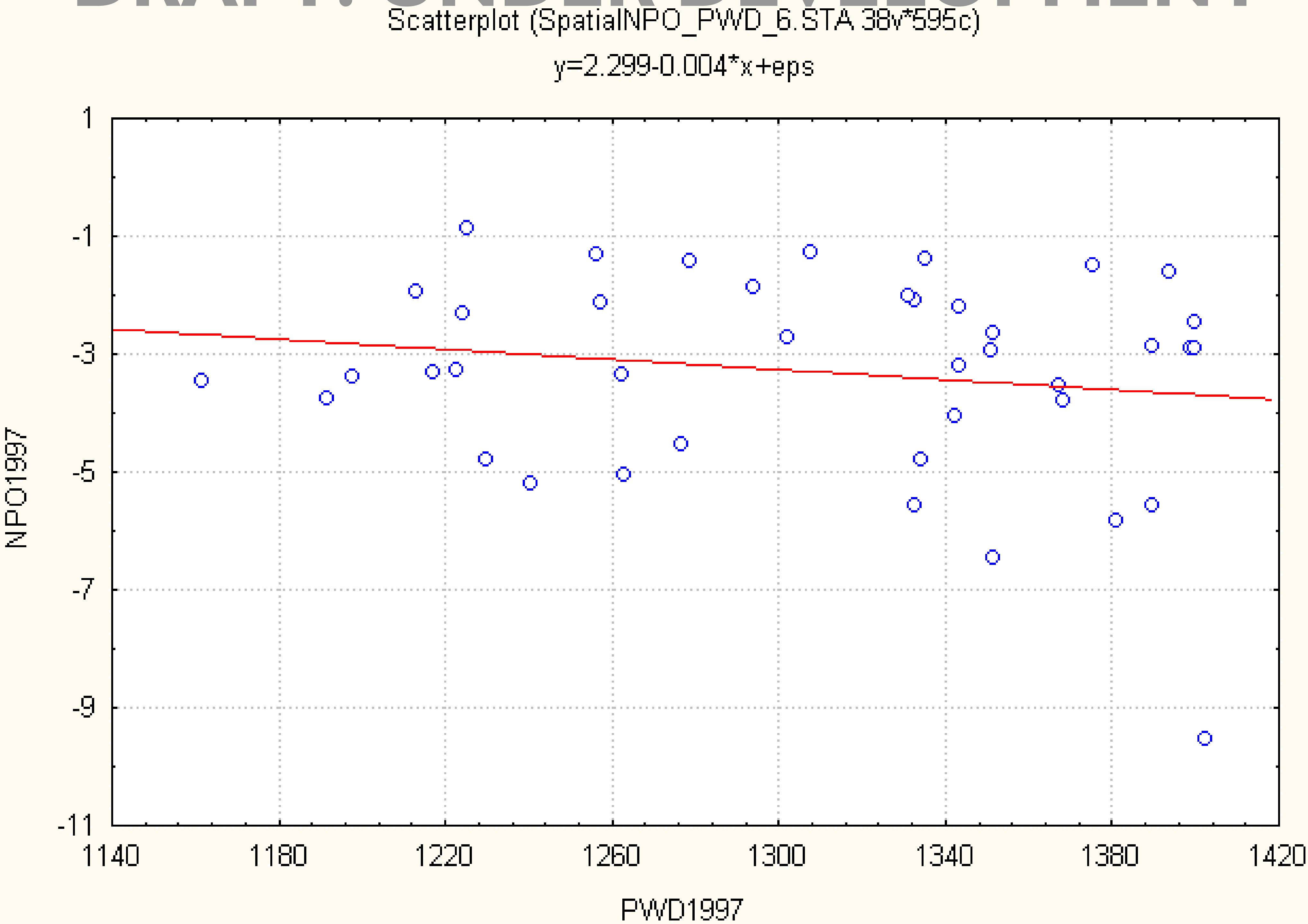
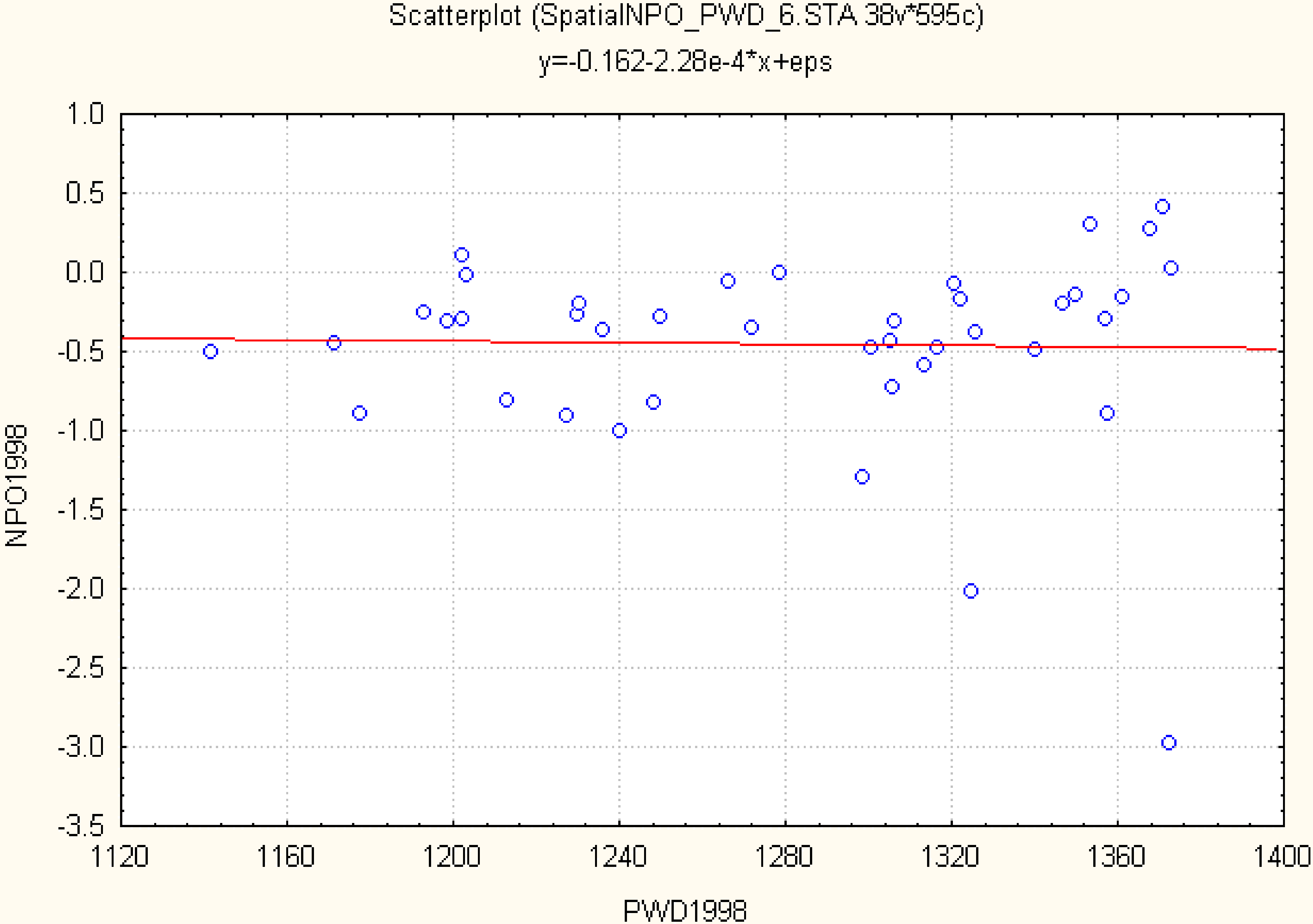



Scatterplot (SpatialNPO_PWD_6.STA 38v*595c)
y=2.299-0.004*x+eps
1
-1
-3
-5
-7
-9
-11
NPO1997
1140
1180
1220
1260
1300
1340
1380
1420
PWD1997

DRAFT: UNDER DEVELOPMENT



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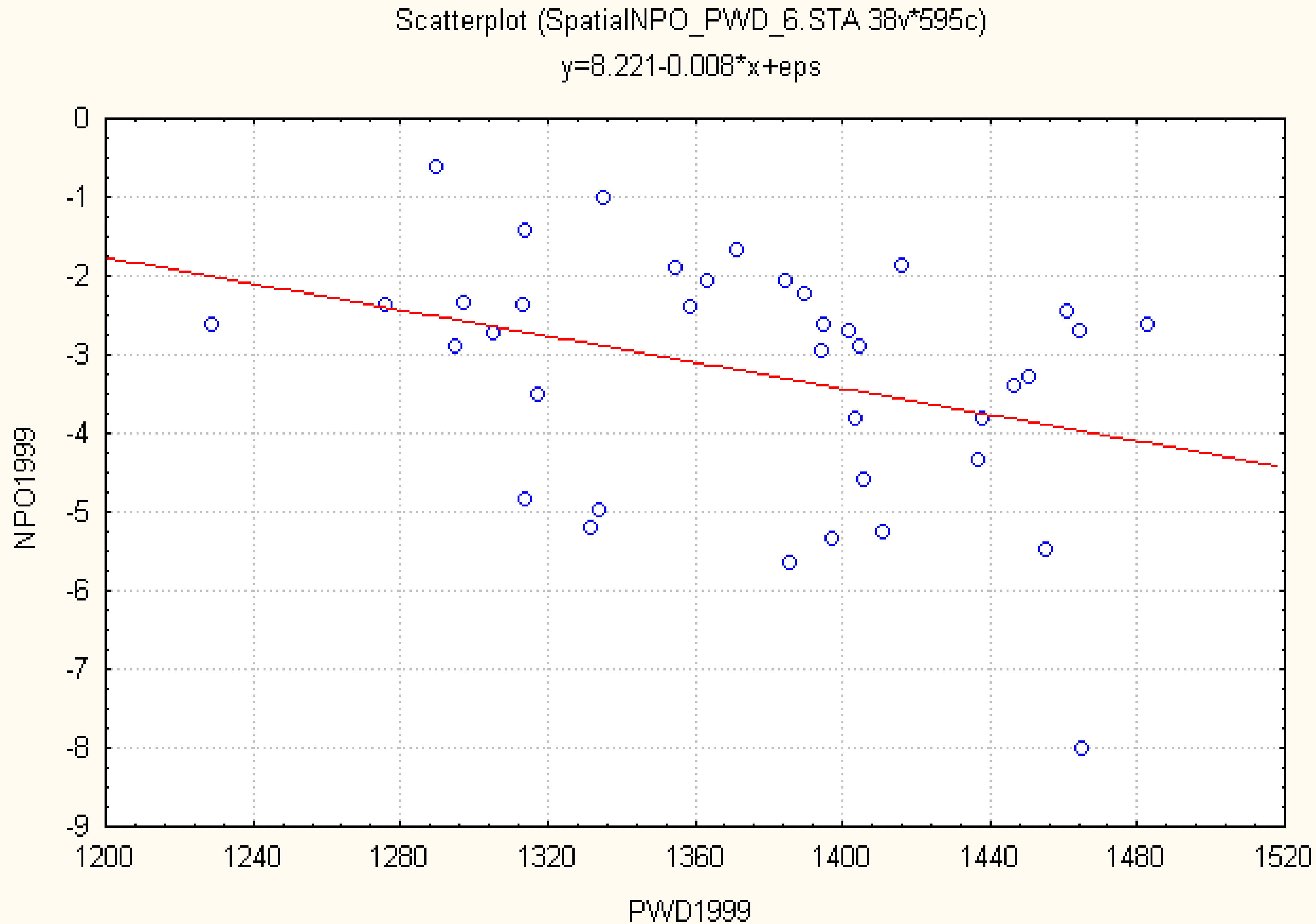
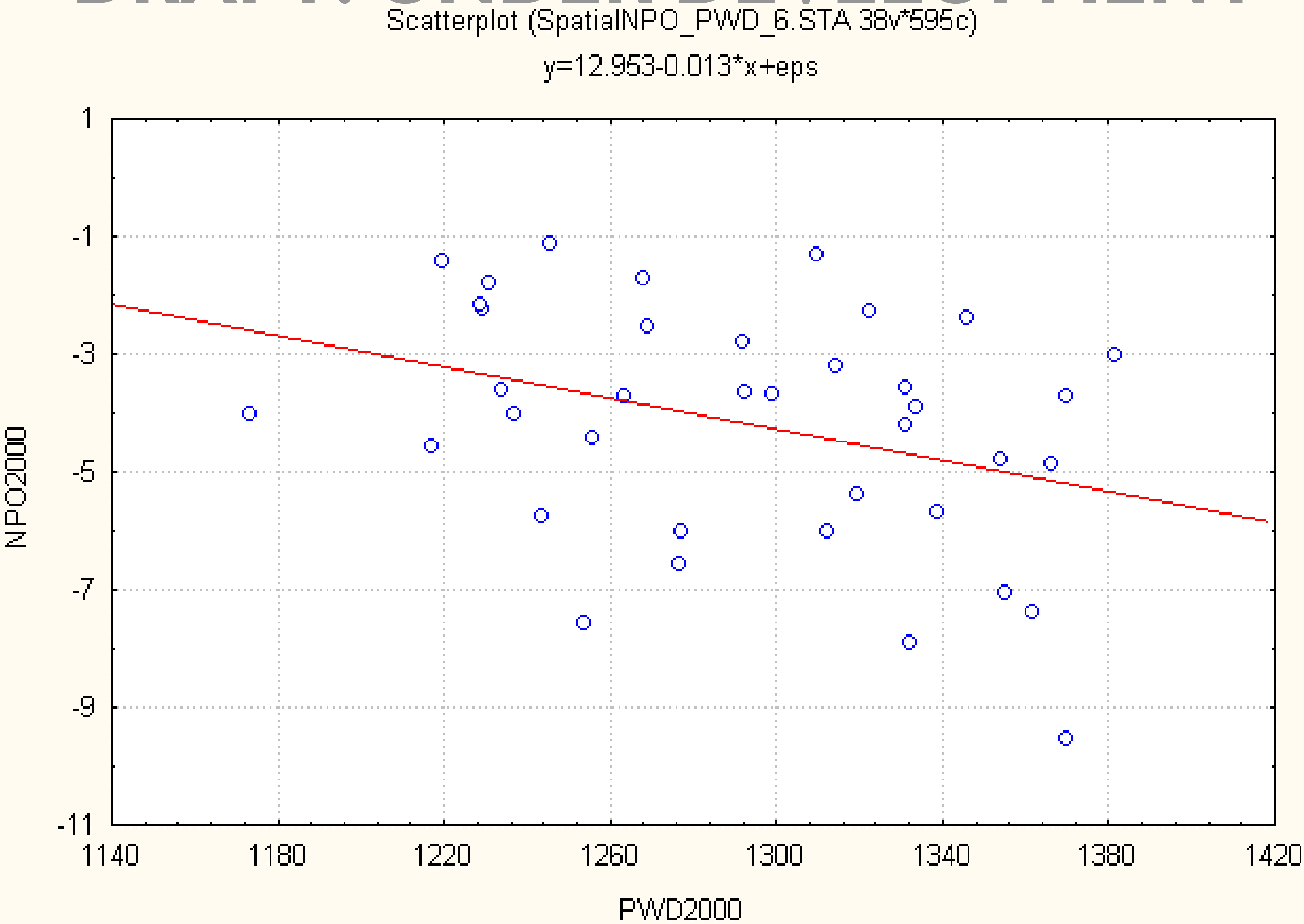
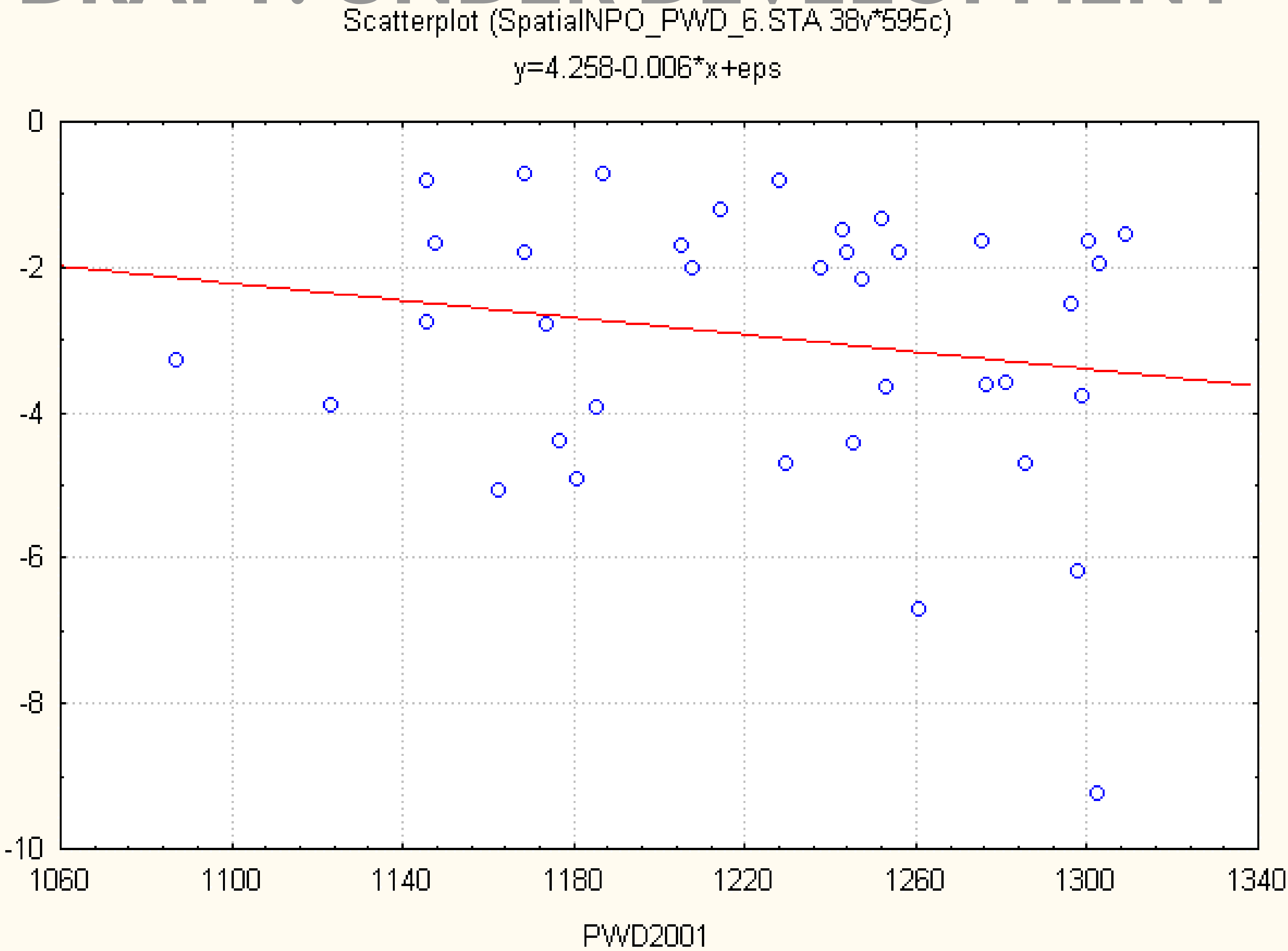
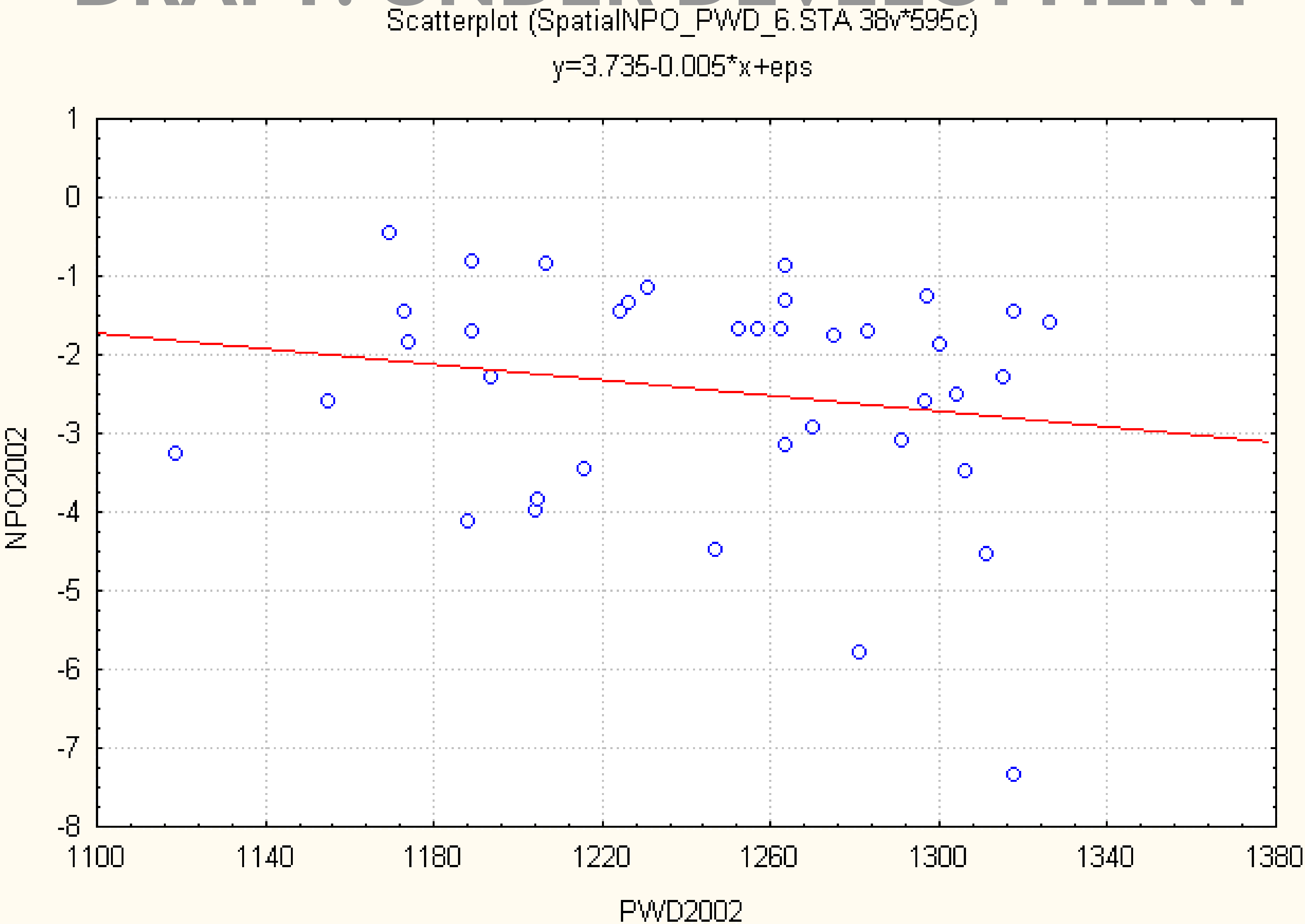



Scatterplot (SpatialNPO_PWD_6.STA 38v*595c)
y=12.953-0.013*x+eps
1
-1
-3
-5
-7
-9
-11
NPO2000
1140
1180
1220
1260
1300
1340
1380
1420
PWD2000

DRAFT: UNDER DEVELOPMENT



DRAFT: UNDER DEVELOPMENT



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Regression Summary: Mesic-associated Sites

Water Year	No. Sites (N)	Regression slope (B)	STD of B	r^2	P-Value
1990	36	-0.004	0.003	0.046	0.210
1991	41	-0.001	0.002	0.005	0.656
1992	39	-0.004	0.004	0.036	0.247
1993	41	-0.002	0.003	0.007	0.596
1994	38	-0.004	0.004	0.035	0.259
1995	41	-0.004	0.002	0.100	0.044
1996	41	-0.002	0.002	0.018	0.399
1997	41	-0.010	0.005	0.085	0.064
1998	40	0.002	0.001	0.068	0.105
1999	38	-0.015	0.005	0.185	0.007
2000	39	-0.006	0.004	0.067	0.111
2001	38	0.000	0.003	0.000	0.974
2002	38	0.002	0.001	0.045	0.202

Significant p-values are shaded in gray.

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Extreme Values of the PWD Index

- NP-1 in WY2001
- 1069 MGY/Log10Ft
- Equivalent to 2596 Ft from 10 MGD source

- S-44 in WY1992
- 1518 MGY/Log10Ft
- Equivalent to 254 Ft from 10 MGD source

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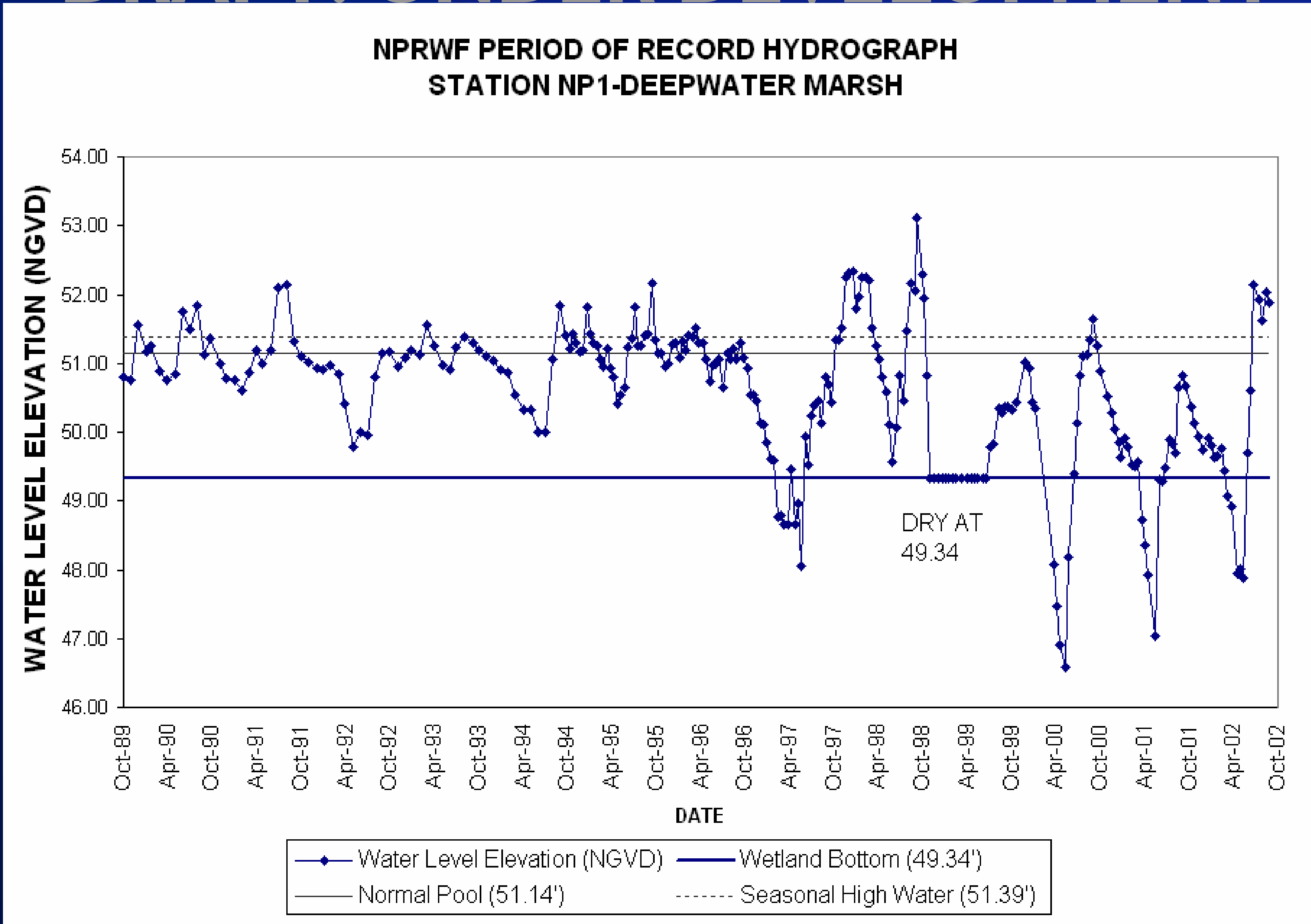
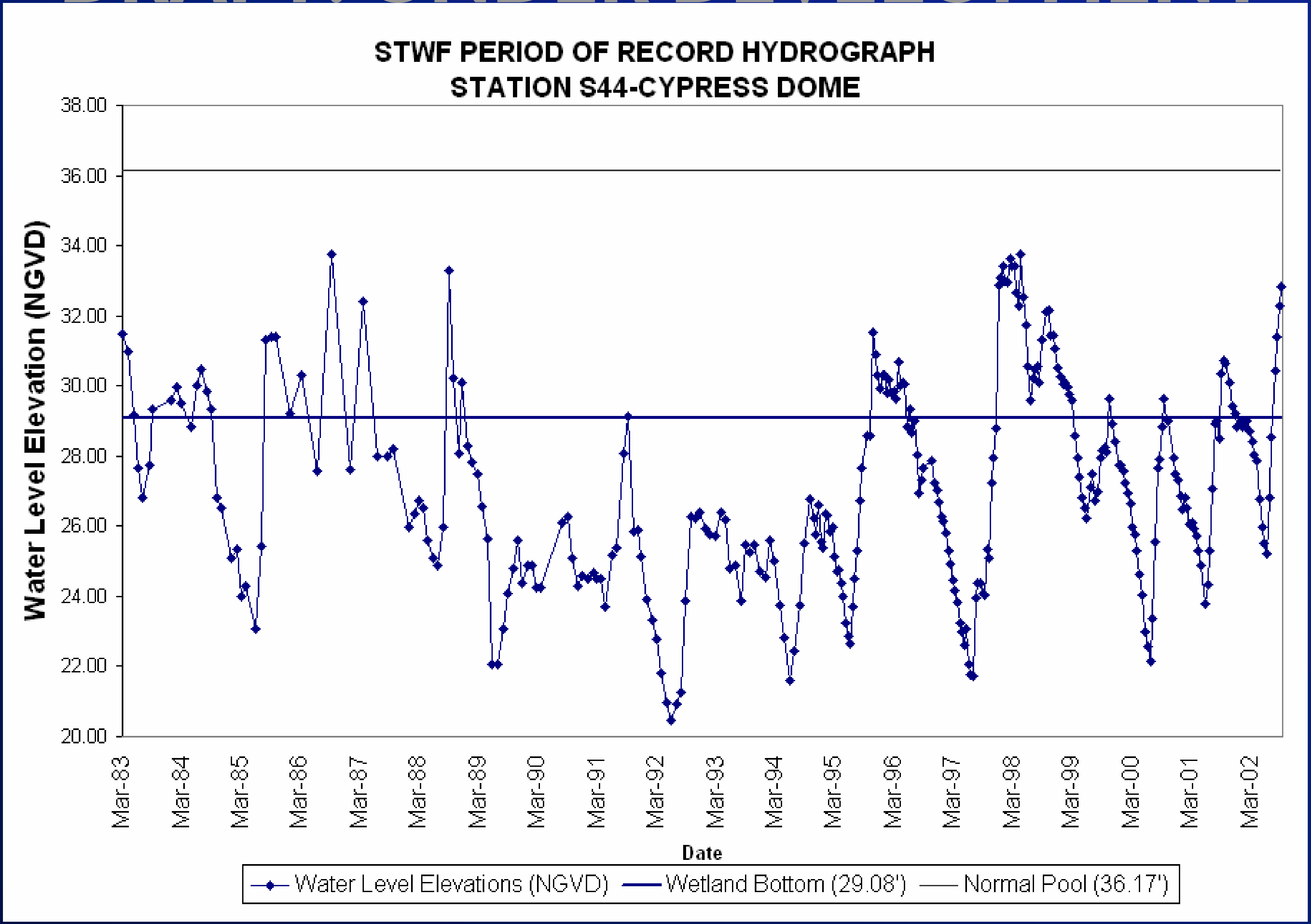
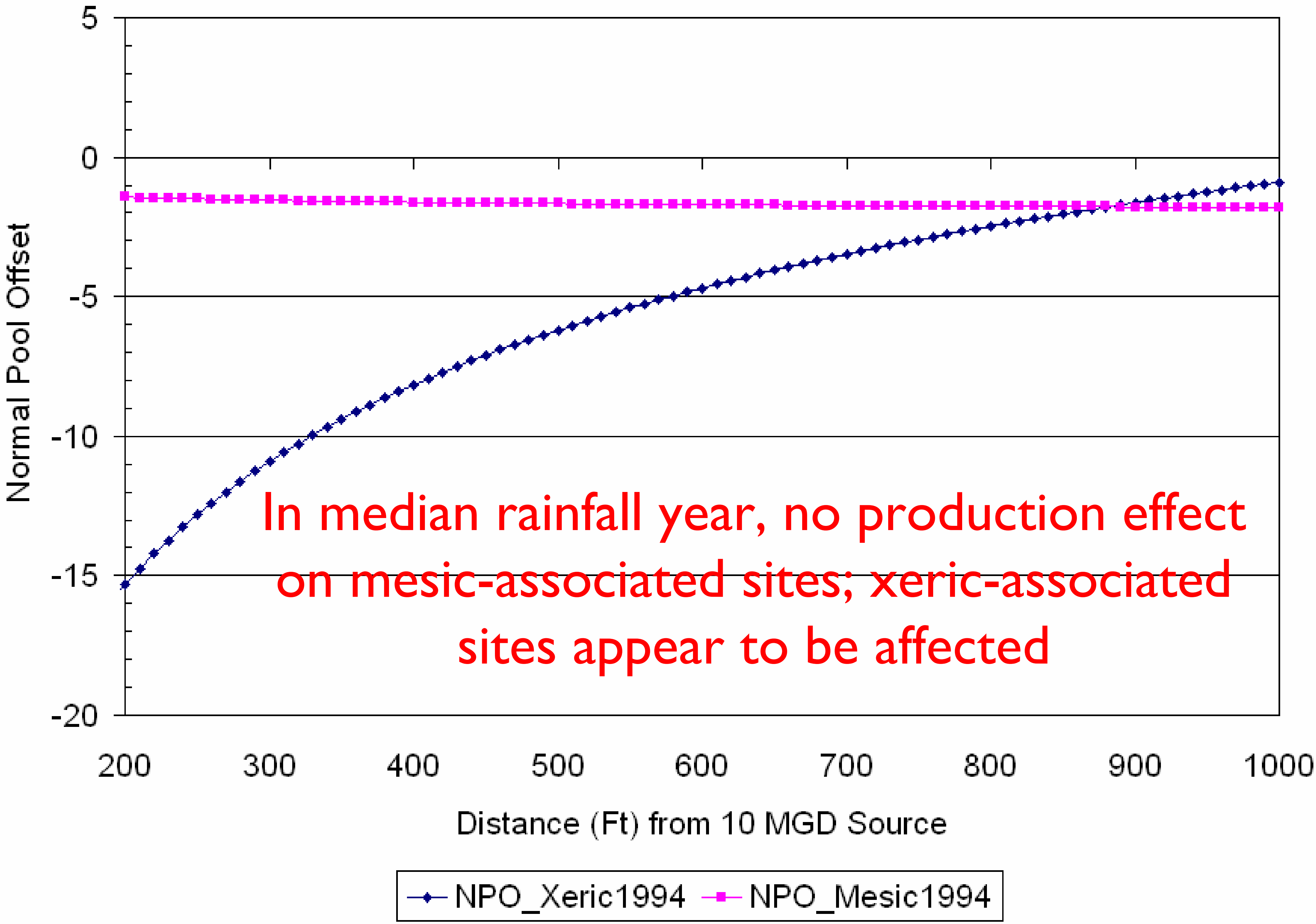


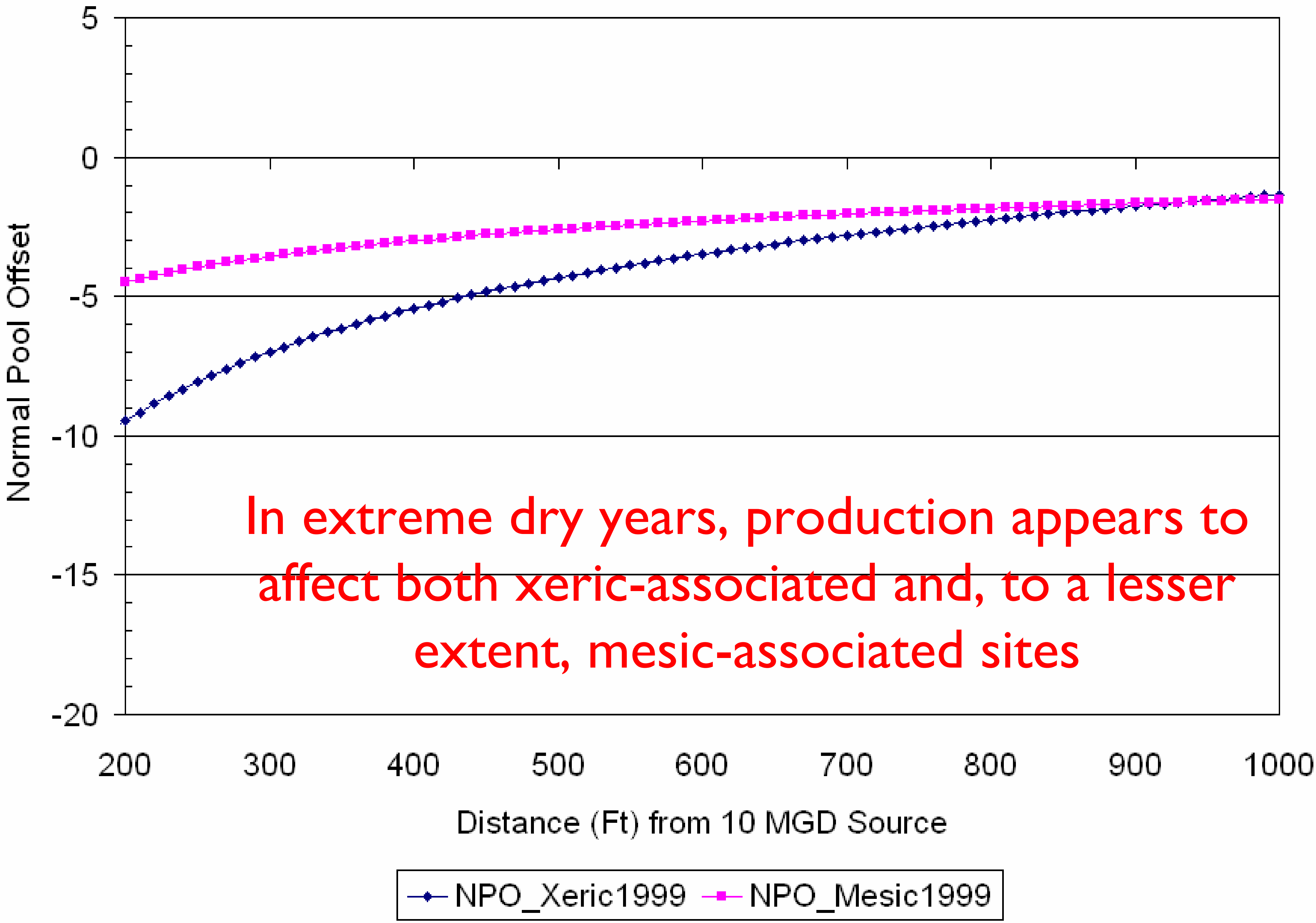
DRAFT: UNDER DEVELOPMENT



DRAFT: UNDER DEVELOPMENT



DRAFT: UNDER DEVELOPMENT



Multivariate Analysis

(xeric-associated sites only)

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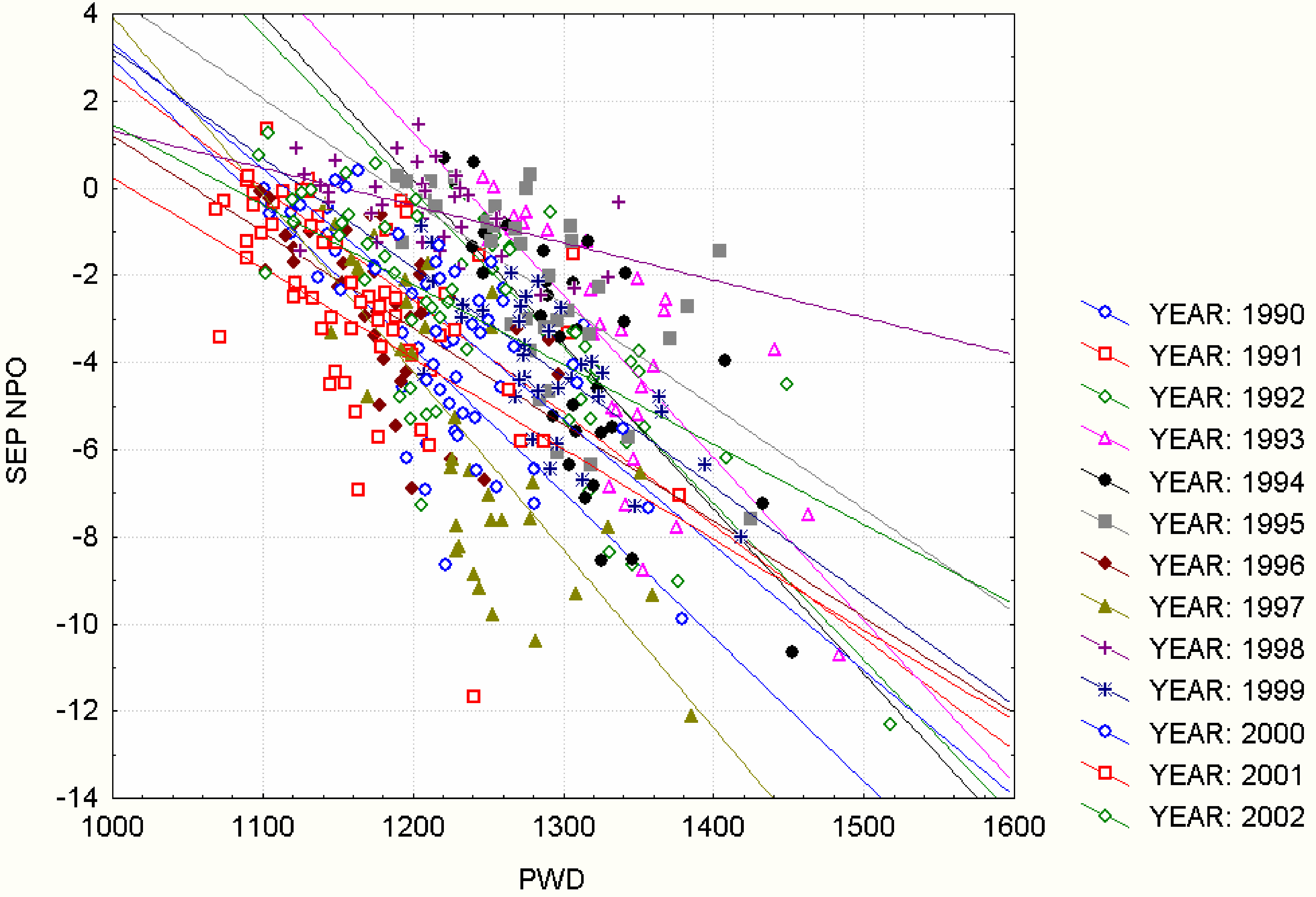

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Multivariate Linear Regression Methods: Predicting Xeric-associated Sep NPOs

Independent variables considered:

- Rainfall
- Rainfall lagged 1 to 3 years
- Departures from mean and median rainfall
- Rainfall intensity (rainfall/rain days)
- Upper Floridan levels
- Lagged PWD 1 to 3 years
- Percent xeric
- Wetland size
- Wetland area:perimeter ratio
- Mean starting wetland water levels (Oct)
- Individual wetland starting water levels (Oct)

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Multivariate Regression Results

		St. Err.		St. Err.		
	BETA	of BETA	B	of B	t(412)	p-level
Intercept			0.944	1.387	0.681	0.496
OCTINPO	0.640	0.032	0.665	0.033	20.010	0.000
PWDI	-0.194	0.032	-0.006	0.001	-6.134	0.000
RAIN1	0.527	0.030	0.108	0.006	17.555	0.000
R= .83335960 R^2= .69448822 Adjusted R^2= .69226361						
F(3,412)=312.19 p<0.0000 Std. Error of estimate: 1.4466, n=416						

Variable Importance:

OctNPO 1.5 x > RAIN 7.4 x > PWD

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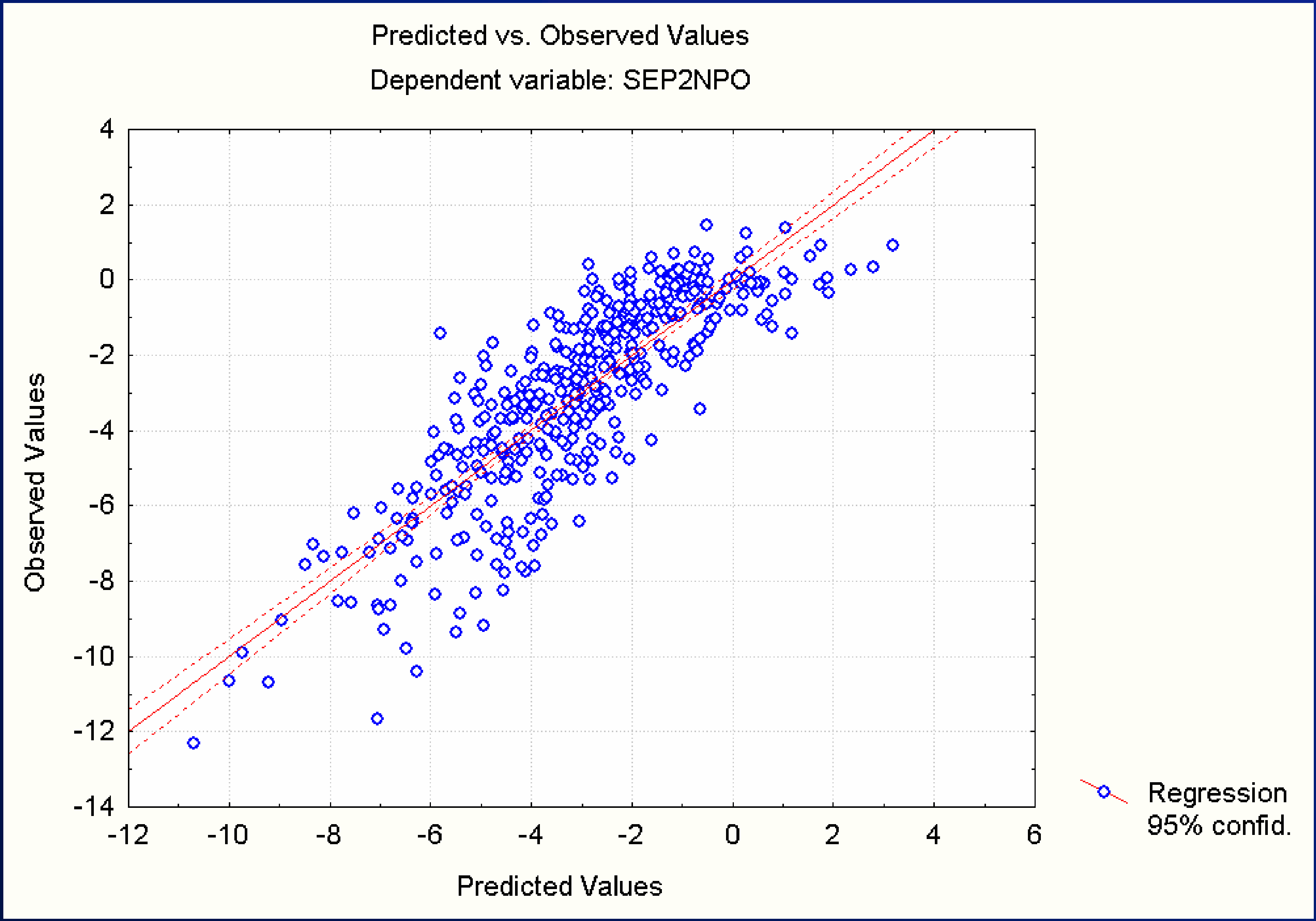

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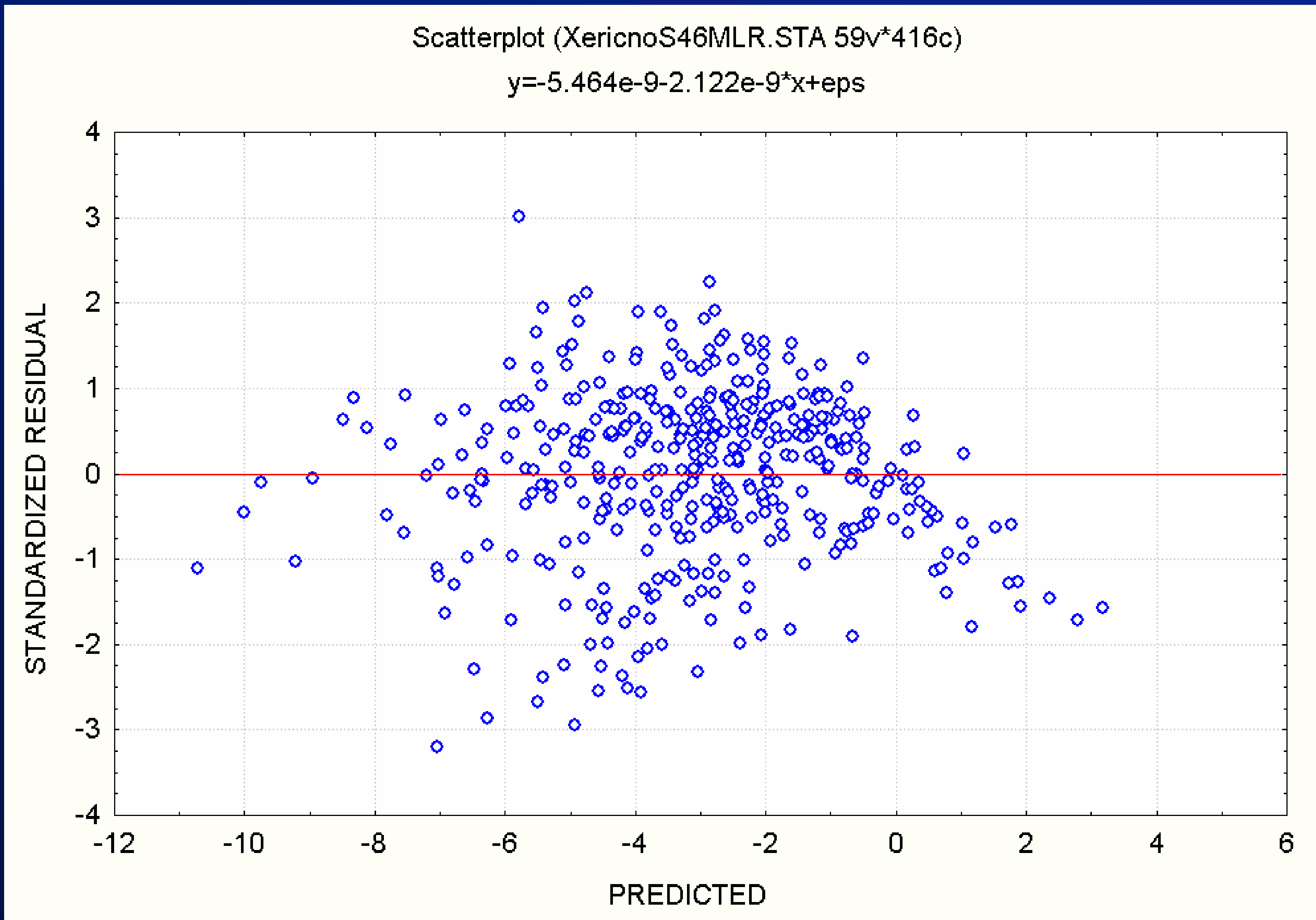
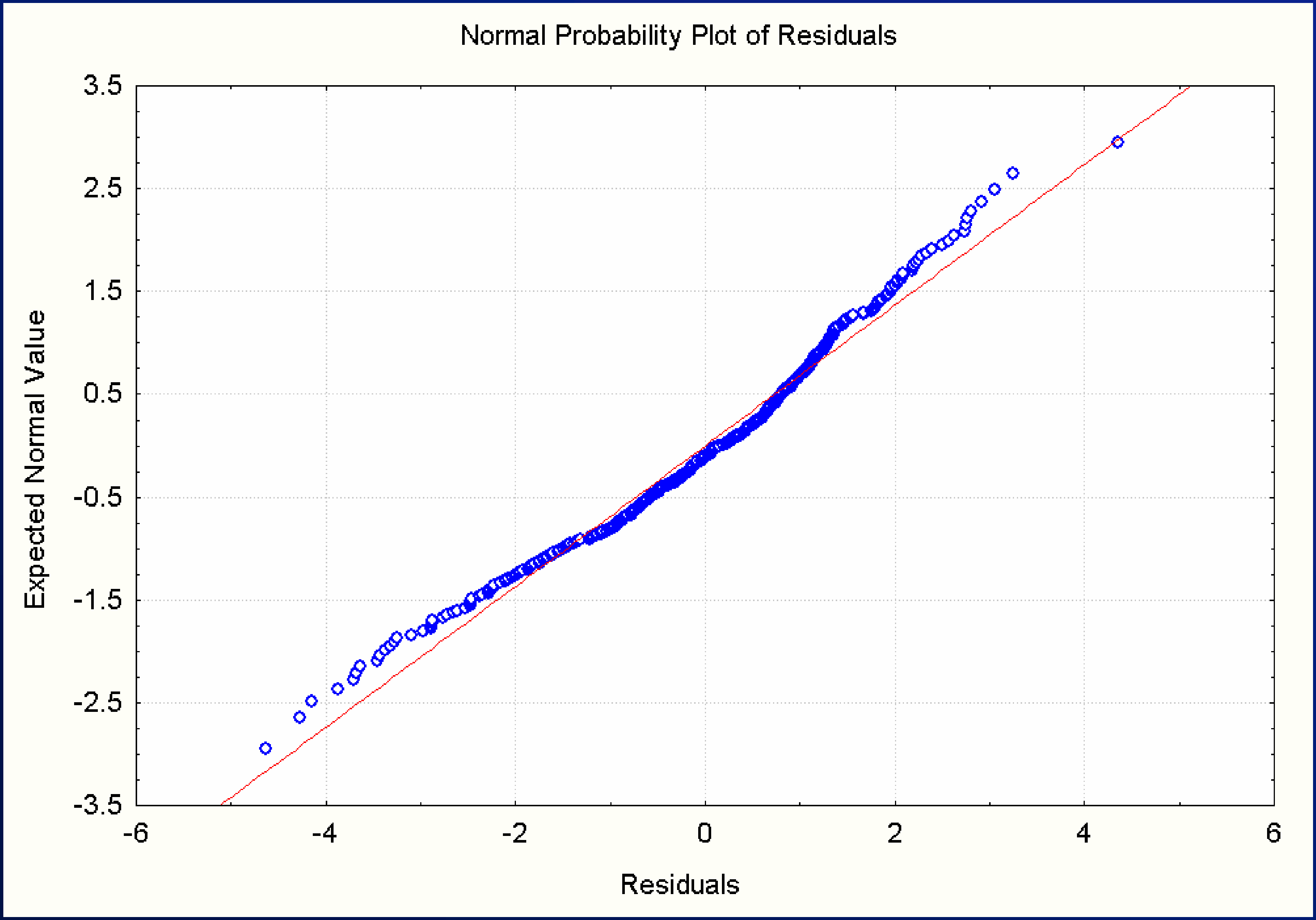
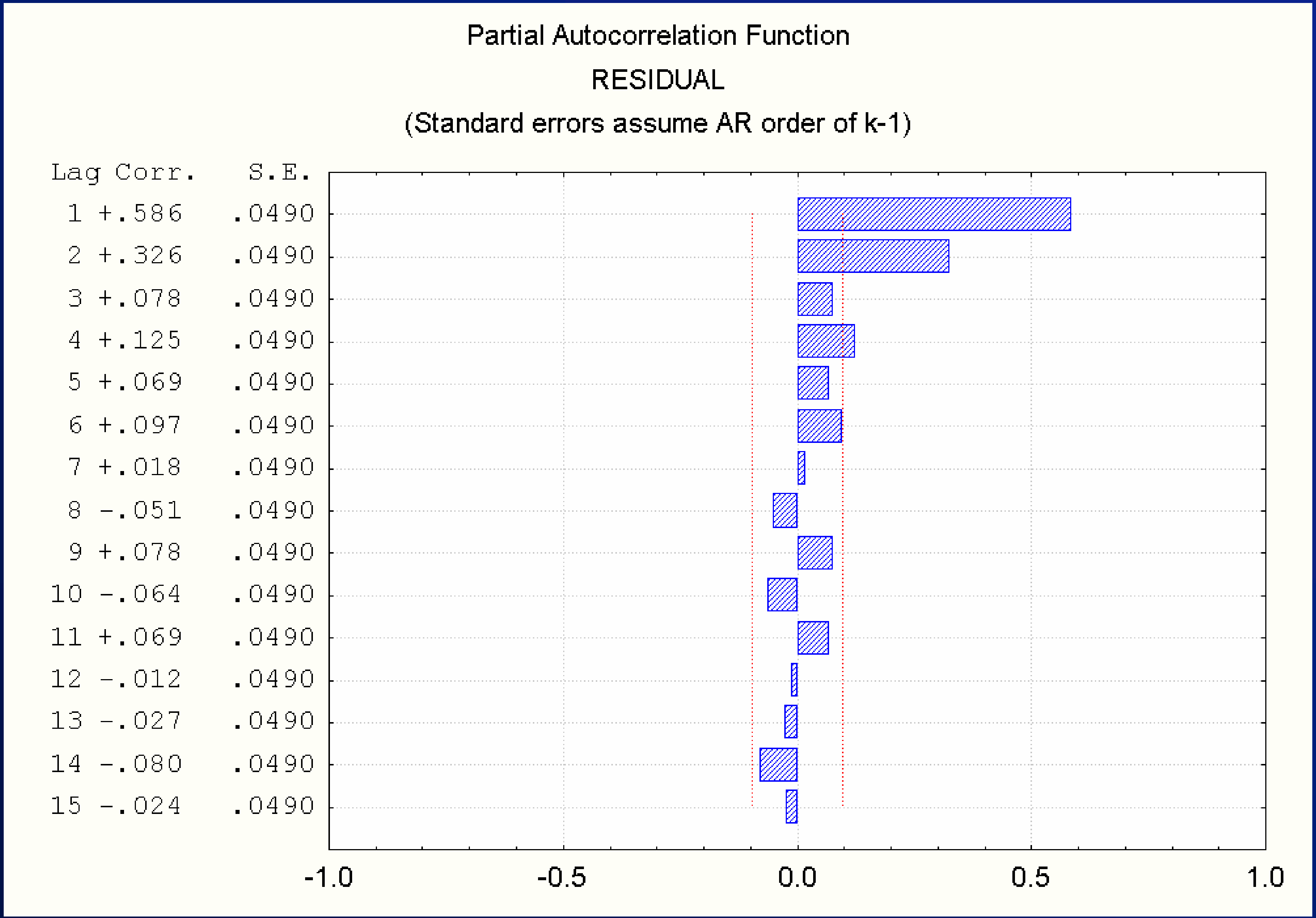


DRAFT: UNDER DEVELOPMENT



DRAFT: UNDER DEVELOPMENT



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Visualizing Model Predictions

	N	Minimum	Lower Quartile	Median	Upper Quartile	Maximum
SEP2NPO	436	-12.31	-4.64	-2.68	-1.04	1.45
PWD1	481	1069	1180	1232	1304	1518
RAIN1	481	38.88	45.41	51.57	54.66	89.66
OCT1NPO	425	-11.39	-4.67	-2.68	-0.99	1.98

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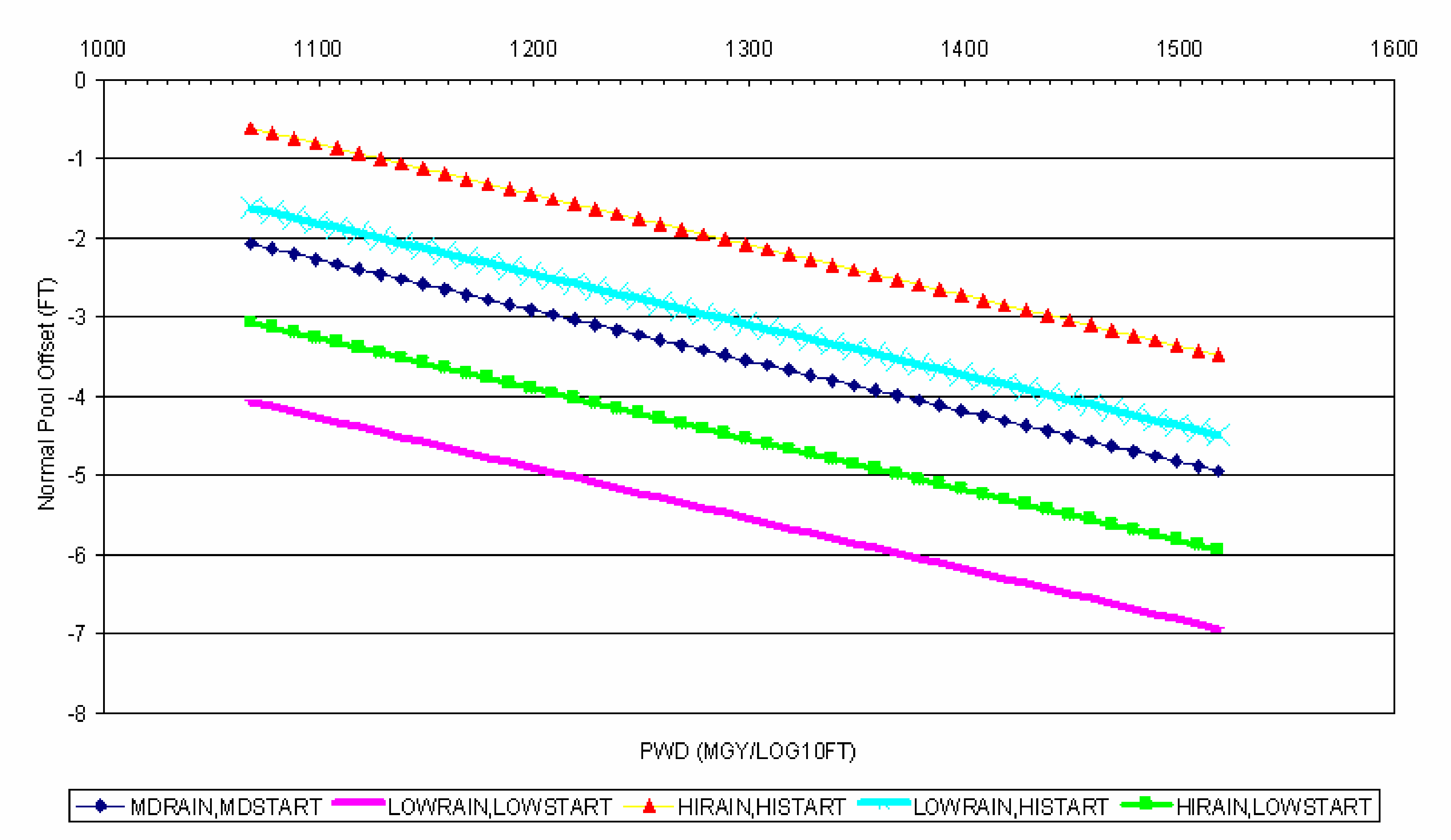
Multivariate Predictions



Conclusions and Future Research*

*more study always needed, but true in this case

Literature review suggests this is the first study to document a log-distance based, linear, additive production effect on surface water features

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As Below, So Above

- Drawdown in observation wells proportional to log distance
- Further thought may clarify relationship of PWD to existing theory

Cooper-Jacob Theis approximation to aquifer drawdown

$$s = \frac{Q}{4\pi T} \ln\left[2.2459 \frac{Tt}{r^2 S}\right]$$

where:

s = drawdown

Q = pumping rate

T = transmissivity

t = time

r = radial distance from pumping well

S = storage coefficient

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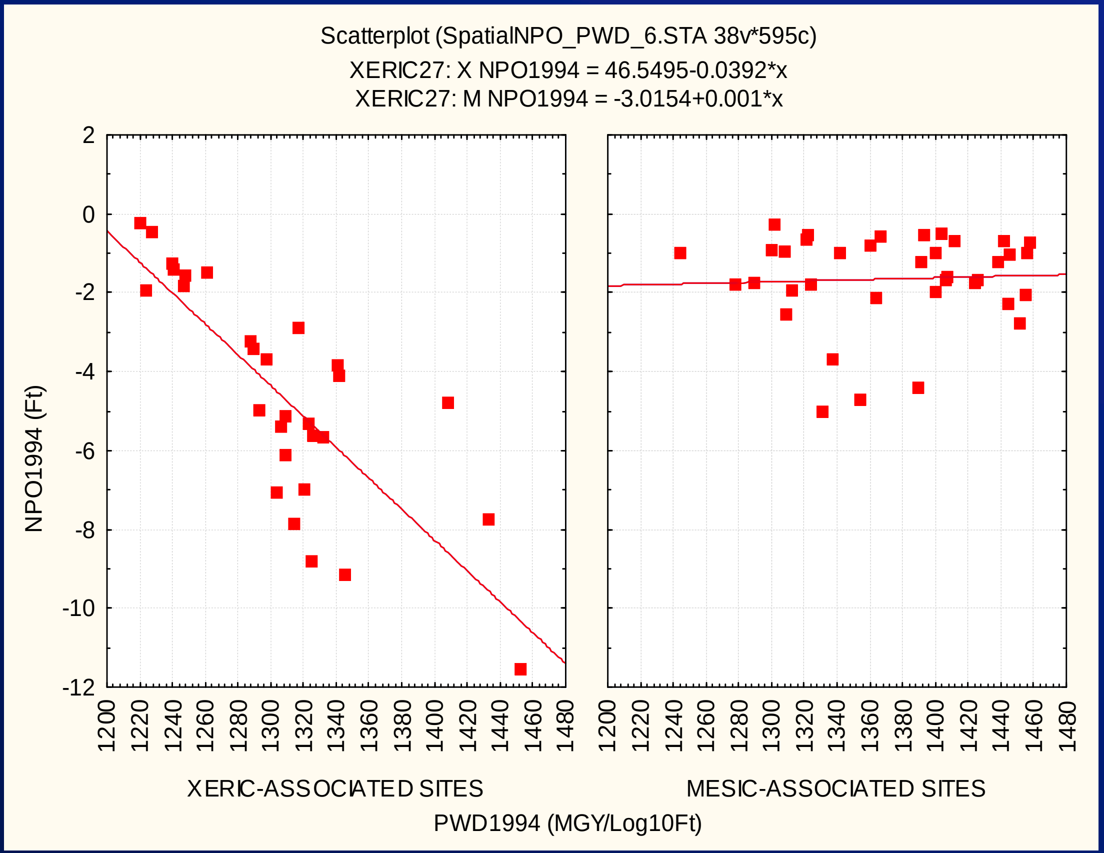
Xeric/mesic-associated wetland water levels differ profoundly in response to production



SJRWMD includes a soil permeability layer in their assessment of likelihood of harm to native vegetation from groundwater production

(Kinser et al. 2003)

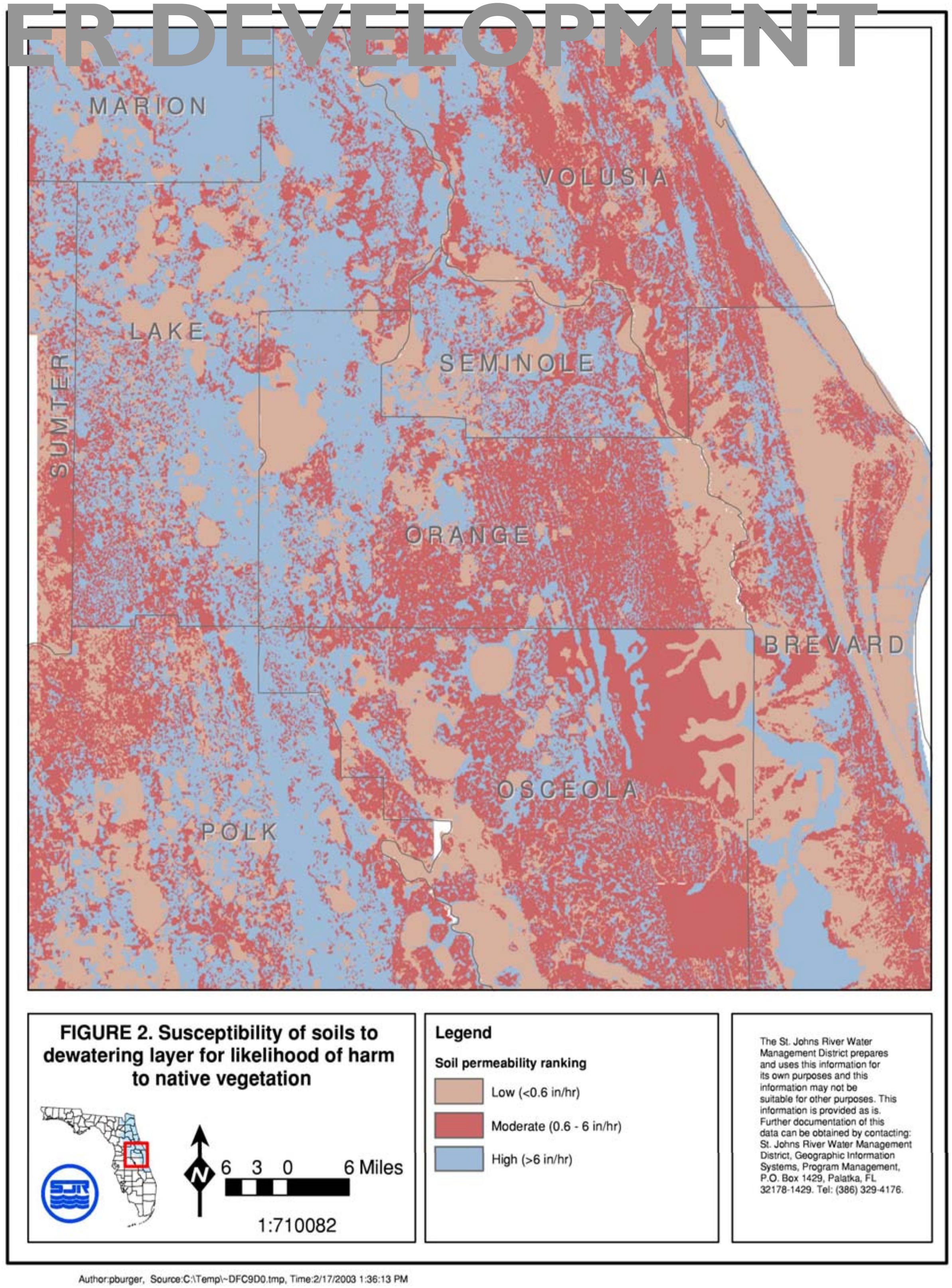


FIGURE 2. Susceptibility of soils to dewatering layer for likelihood of harm to native vegetation

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Recommend validating statistical model using out-of-sample data (WY2003 – WY2007)

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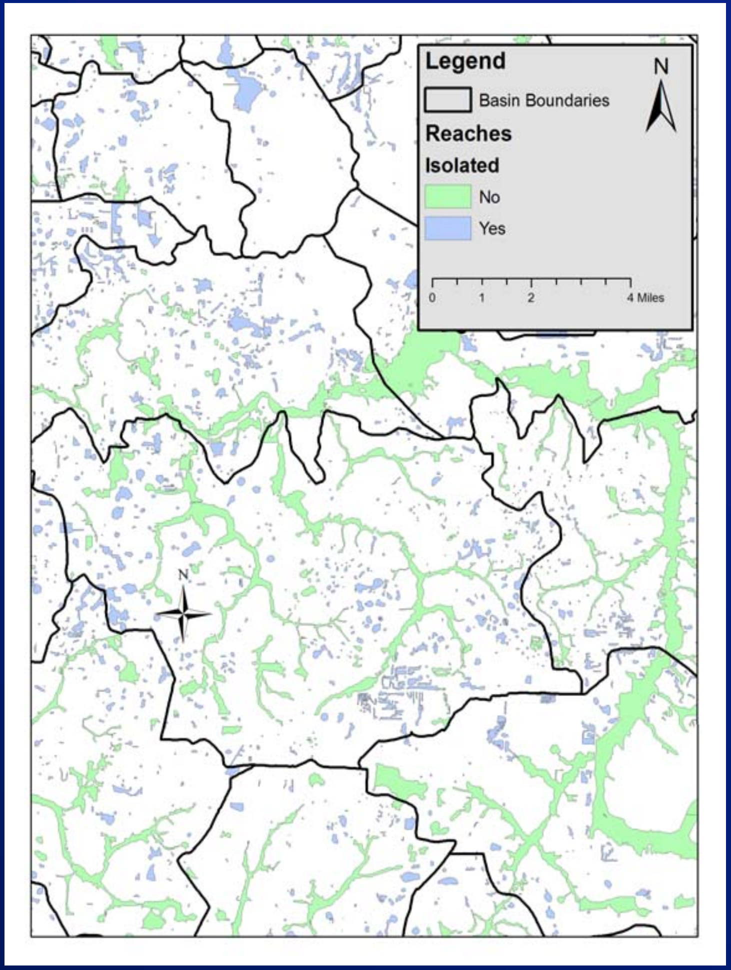
Recommend incorporating xeric soils layer in INTB predictions of surface water level levels/hydroperiods



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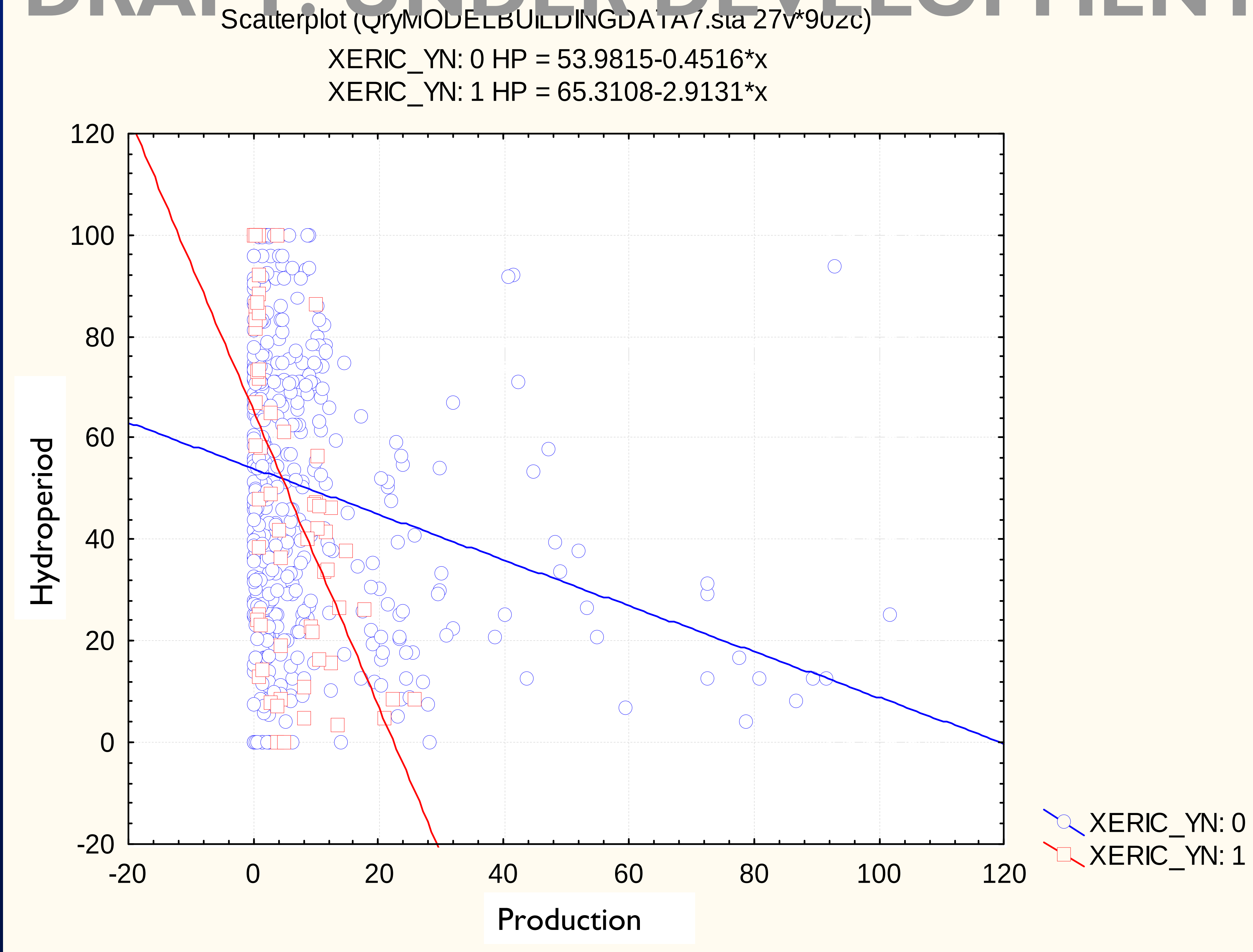

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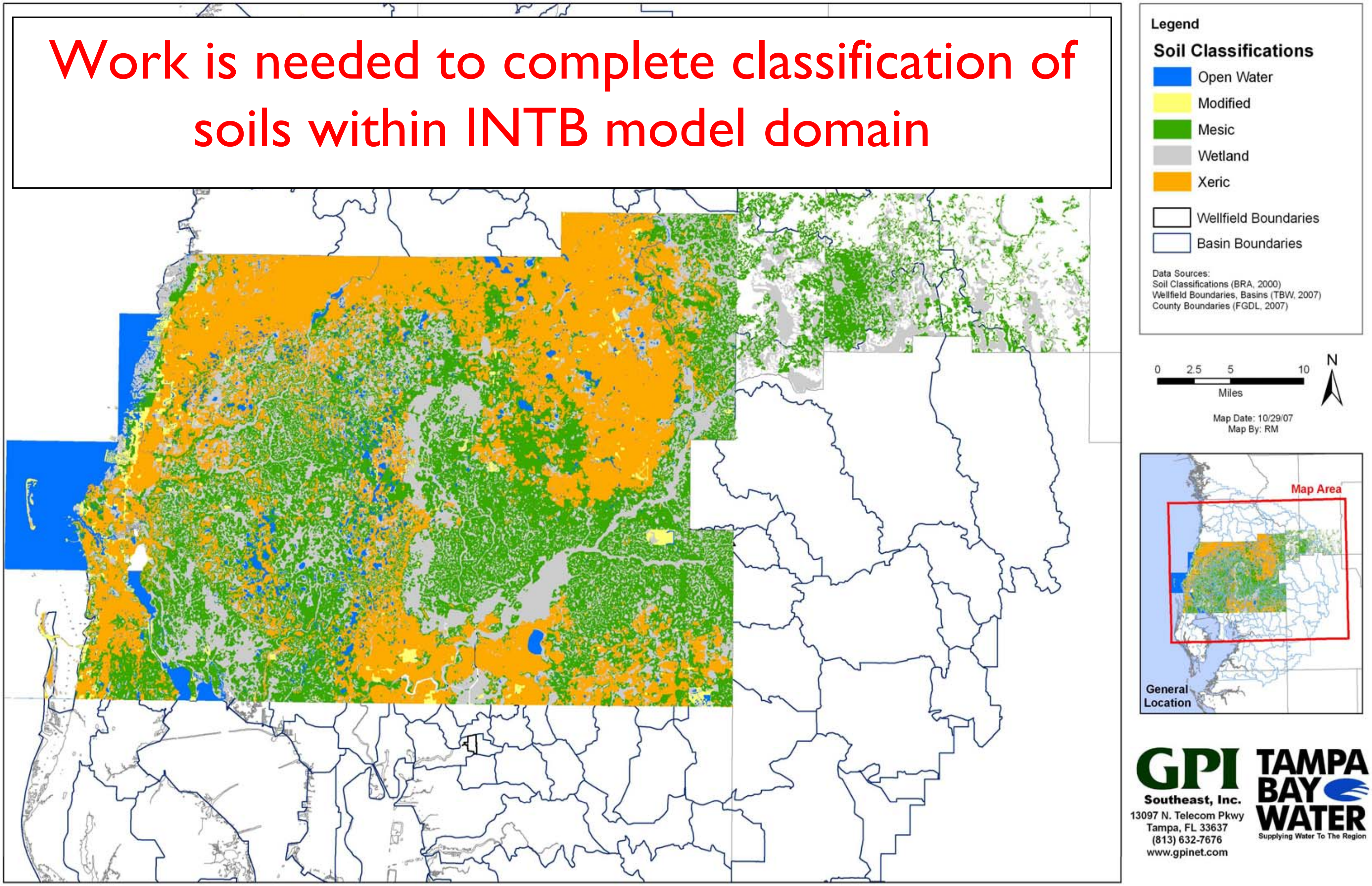
Work is needed to complete classification of soils within INTB model domain



(GPI Southeast, Inc. 2008)

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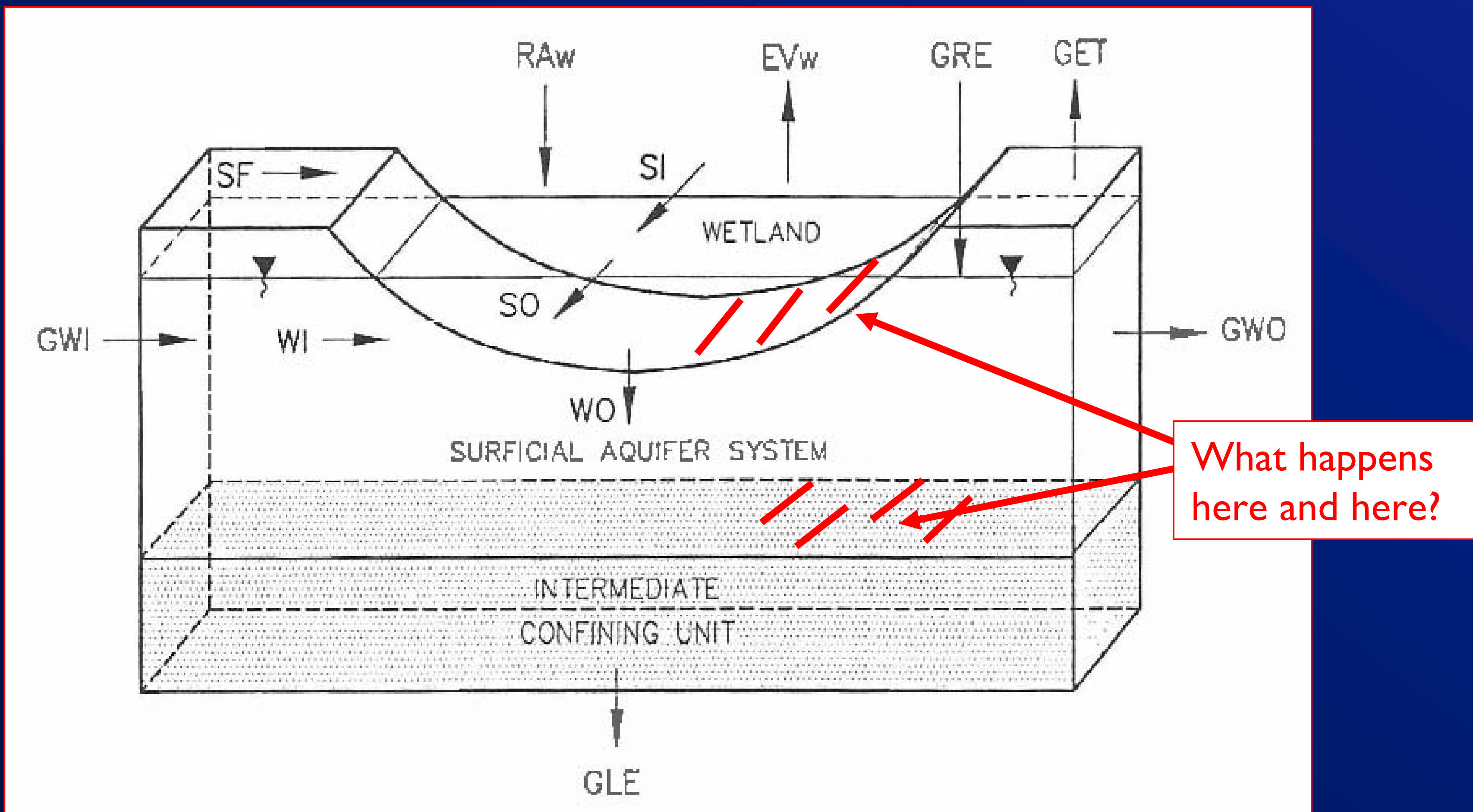
What is the role of wetland soil permeability vs. the role of leakance (variable confinement)?



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Speculations…

Hydraulic conductivity of organic sediments lining wetlands varies by 11 orders of magnitude (Wise et al. 2000).

Leakage through sides of wetlands may be primary mode of infiltration in some cases (Heimburg 1984).

Infiltration rates may be generally higher for wetlands topographically higher in the landscape (Darcy's Law).

Xeric soil areas may be correlated with reduced confinement between SAS and Floridan (Cathleen Jonas).

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Suggesting experiments…

Examine spatial correlation between leakance and xeric soils.

Study soil boring logs from xeric- and mesic-associated sites.

Review synoptic changes in SAS levels in the vicinity of xeric- and mesic-associated sites.


DRAFT: UNDER DEVELOPMENT
Questions?
suggestions or requests to
dschmutz@gpinet.com