

## APPENDIX C

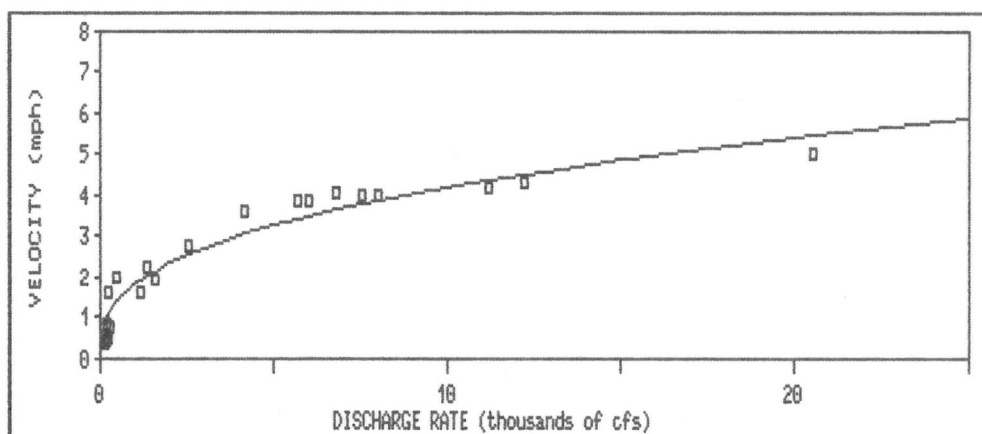
### Water Speed Data

These data were obtained from the Santa Rosa field office of the U.S. Geological Survey and analyzed to provide plots of average cross-sectional water speed vs. discharge rate. Included for the gauges near Hopland, Cloverdale, Healdsburg, and Guerneville are:

- 1 - explanation of methodology
- 2 - raw data consisting of speeds and average cross-sectional speeds
- 3 - transformed (natural log and 1/i exponent) data and least squares regression analysis
- 4 - computer-generated plots of fit-by-eye and regression lines for average cross-sectional water speed vs discharge rate at each gauge location
- 5 - summary table of regressed speeds at ten discharge rates and the actual discharge rates measured during the formalin spill of March, 1987.

Average velocities and discharge rates for gauging stations at Largo, Cumiskey, Healdsburg and Hacienda were obtained from the USGS field office in Santa Rosa. The average velocity measurements were calculated and converted from fps to mph and then plotted against the discharge. The data conformed to a power curve where velocity was a function of discharge raised to a fraction (1/"i" or "i<sup>th</sup>" root). The data were subjected to a least-squares regression analysis (Steel and Torrie, 1960) after transforming discharge to an "i<sup>th</sup>" root. The best fit was determined by iteration at varying "i<sup>th</sup>" roots, the highest coefficient of determination ( $r^2$ ) concluding the analysis. Coefficients of determination ranged from 0.8488 (Guerneville) to 0.9597 (Healdsburg).

The following figure is an example of the raw data and a regression line for the Cloverdale gauge (additional plots are located in section 4 of this appendix).



Since the ascending limb has such a high rate of change (velocity increasing at a high rate with respect to discharge), velocity estimates below 1000 cfs are not reliable. In the case of the Guerneville data, velocities at a discharge rate less than 500 cfs were measured at a different site, thus velocities from discharges of 500 cfs or larger were used to derive the velocity vs. discharge relationship. Velocities were taken from the plots at ten discharge rates by two methods: fit-by-eye and least-squares regression (Table C.1). Discharge rates were set uniformly downstream, i.e. the discharge used at Hopland was used at Guerneville.

A velocity at a specific discharge rate was set to apply for the site where measured, plus one-half the distance from said site to the next gauging site in both the upstream and downstream directions. That is, the velocity measured at Cumiskey station was applied to a section from a point half-way from Largo to Cumiskey (upstream) to a point half-way between Cumiskey and Healdsburg (downstream). For comparison, travel times were calculated from town to town rather than gauge to gauge.

Admittedly, the velocities represent an instantaneous measurement at only one point in many miles of a river section. Consequently, these are only rough estimates of travel time. As expected, cumulative travel time decreased with increased discharge rate, i.e. the slopes of the cumulative travel time curves decreased with increased discharge rate (Table C.2).

Due to the deficiency of velocity measurements for low discharge rates from which the discharge/velocity plots were made, actual measurements of velocity were taken by Regional Board staff at sixteen sites on the Russian River from the Forks to Odd Fellows Bridge near Korbek in June of 1987. The travel times were calculated as above.

Table C.1. Comparison of average velocity measurements from fit-by-eye and regressed curves of average velocity versus discharge rate.

<u>Discharge</u>	<u>Largo*</u>	<u>Cummisk</u>	<u>Healds</u>	<u>Hacienda</u>
218-313	1.38	0.63	1.05/1.76	1.83
400				
Regressed	1.42	1.32	1.0	0.78
1000				
Eye-Fit	2.0	2.0	1.4	0.6
Regressed	1.9	1.84	1.44	1.06
2000				
Eye-Fit	2.7	2.7	1.9	1.0
Regressed	2.37	2.36	1.90	1.34
4000				
Regressed	2.96	3.03	2.50	1.69
6000				
Eye-Fit	3.6	3.9	2.9	2.0
Regressed	3.37	3.51	2.94	1.93
8000				
Regressed	3.69	3.89	3.30	2.13
10,000				
Eye-Fit	3.6	4.3	3.6	2.29
Regressed	3.97	4.22	3.60	2.58
15,000				
Eye-Fit	3.6	4.6	4.2	3.0
Regressed	3.97	4.88	4.23	2.62
20,000				
Eye-Fit	3.6	4.7	4.8	3.2
Regressed	3.97	5.42	4.74	2.89
40,000				
Regressed	3.97	6.95	6.24	3.64

\* Velocity at Largo gauge was held constant for discharge rates of 10,000 cfs and more since it is unlikely that discharge will ever exceed that value

Note: Largo = closest gauge to Hopland  
 Cummisk = Cummiskey Station Road gauge, upstream of Cloverdale  
 Healds = Healdsburg gauge  
 Hacienda = Hacienda Bridge gauge at Hacienda near Guerneville

Table C.2. Summary of cumulative travel time (hours) for regressed and fit-by-eye velocities for the Russian River between the Forks and Guerneville.

<u>Discharge</u>	<u>Cummulative time from the Forks to:</u>				
	<u>Hopland</u>	<u>Clovd1.</u>	<u>Hldsbg.</u>	<u>Wohler</u>	<u>Grnv11.</u>
218-313					
Measured	16.1	33.9	74.3	79.8	87.3
400					
Eye Fit					
Regressed	13.5	24.8	52.7	61.5	73.7
1000					
Eye Fit	9.6	17.1	36.6	45.5	61.3
Regressed	10.1	18.2	37.8	44.1	53.1
2000					
Eye Fit	7.1	12.7	27.0	32.8	42.3
Regressed	8.1	14.5	29.4	34.3	41.4
4000					
Eye Fit					
Regressed	6.5	11.7	22.9	26.7	32.3
6000					
Eye Fit	5.3	9.2	18.8	22.0	26.8
Regressed	5.7	10.0	19.8	23.1	28.0
8000					
Eye Fit					
Regressed	5.2	9.1	17.8	20.8	25.2
10,000					
Eye Fit	5.3	8.9	16.9	19.5	23.3
Regressed	4.8	8.4	16.4	19.2	23.3
15,000					
Eye Fit	5.3	8.7	15.7	17.9	21.1
Regressed	4.8	8.0	14.8	17.2	20.8
20,000					
Eye Fit	5.3	8.6	15.0	17.0	20.0
Regressed	4.8	7.7	13.9	16.0	19.3
40,000					
Regressed	4.8	7.2	11.9	13.5	16.2

Measured - velocities measured in June of 1987

Eye Fit - best curve fit-by-eye through raw velocity data

Regressed - root function curve obtained by least squares regression

U.S.G.S. SPEEDS AT GAUGING STATIONS ON THE RUSSIAN RIVER

HOPLAND RAW DATA

DISCHARGE RATES (CFS):

238	567	1572	9178
*****SPEED*****			
(FPS)	(FPS)	(FPS)	(FPS)
0.565	0.292	1.49	1.8
0.968	0.838	2	2.35
1.29	1.01	2.61	2.04
1.32	0.988	3.74	3.12
1.47	1.56	4.6	3.5
1.8	1.67	4.68	4.22
1.76	1.84	4.56	4.4
1.76	1.84	2.96	4.58
1.84	1.91	4.48	5.35
2.05	1.88	4.37	5.63
2	1.93	4.55	5.88
2.05	1.86	4.75	6.3
1.73	1.8	4.85	6.32
1.73	1.93	4.96	6.6
1.96	1.88	4.65	6.74
1.96	1.9	4.46	6.92
1.88	1.94	4.26	6.98
2.1	1.83	4.37	7.07
2.2	1.86	4.16	6.94
1.92	1.88	3.57	6.8
2	1.86	3.98	6.72
1.8	1.76	3.72	6.51
1.8	1.73	3.57	6.51
1.44	1.47	3.14	6.08
1.41	1.44	1.18	5.2
0.968	1.11	1.71	5.81
0.928	0.875	1.54	5.68
	0.731	1.23	5.63
1.66			5.46
	1.56	3.58	5.08
			4.56
			3.84
			3.13
			2.5
			2.05
			1.01

HOPLAND SUMMARY

DISCHARGE	SPEED	
(CFS)	(FPS)	(MPH)
148 *	1.78	1.21
150 *	1.80	1.23
164 *	1.48	1.01
176 *	1.40	0.96
211 *	1.24	0.84
236 *	1.78	1.21
238	1.66	1.13
259 *	1.35	0.92
567	1.56	1.06
1000 *	2.97	2.03
1020 *	2.48	1.69
1570 *	3.70	2.53
1572	3.58	2.44
5040	5.32	3.63
5080	5.03	3.43
5590	4.99	3.40
6160	5.32	3.63
6830	5.38	3.67
9178	4.98	3.40
9200	5	3.41

\* Additional raw data  
V = Discharge/Area

Hopland - Largo Gauge

Q	Vel (mph)
148	1.21
150	1.23
164	1.01
176	0.96
211	0.84
236	1.21
238	1.13
259	0.92
567	1.06
1000	2.03
1020	1.69
1570	2.53
1572	2.44
5040	3.63
5080	3.43
5590	3.40
6160	3.63
6830	3.67
9178	3.40
9200	3.41

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 Selected Regression:  $Y = 0.2082 \times X^{(1.3.19)}$

Std Err of Y Est	0.286939
R Squared	0.935576
No. of Observations	20
Degrees of Freedom	19
X Coefficient(s)	0.208182
Std Err of Coef.	0.005584

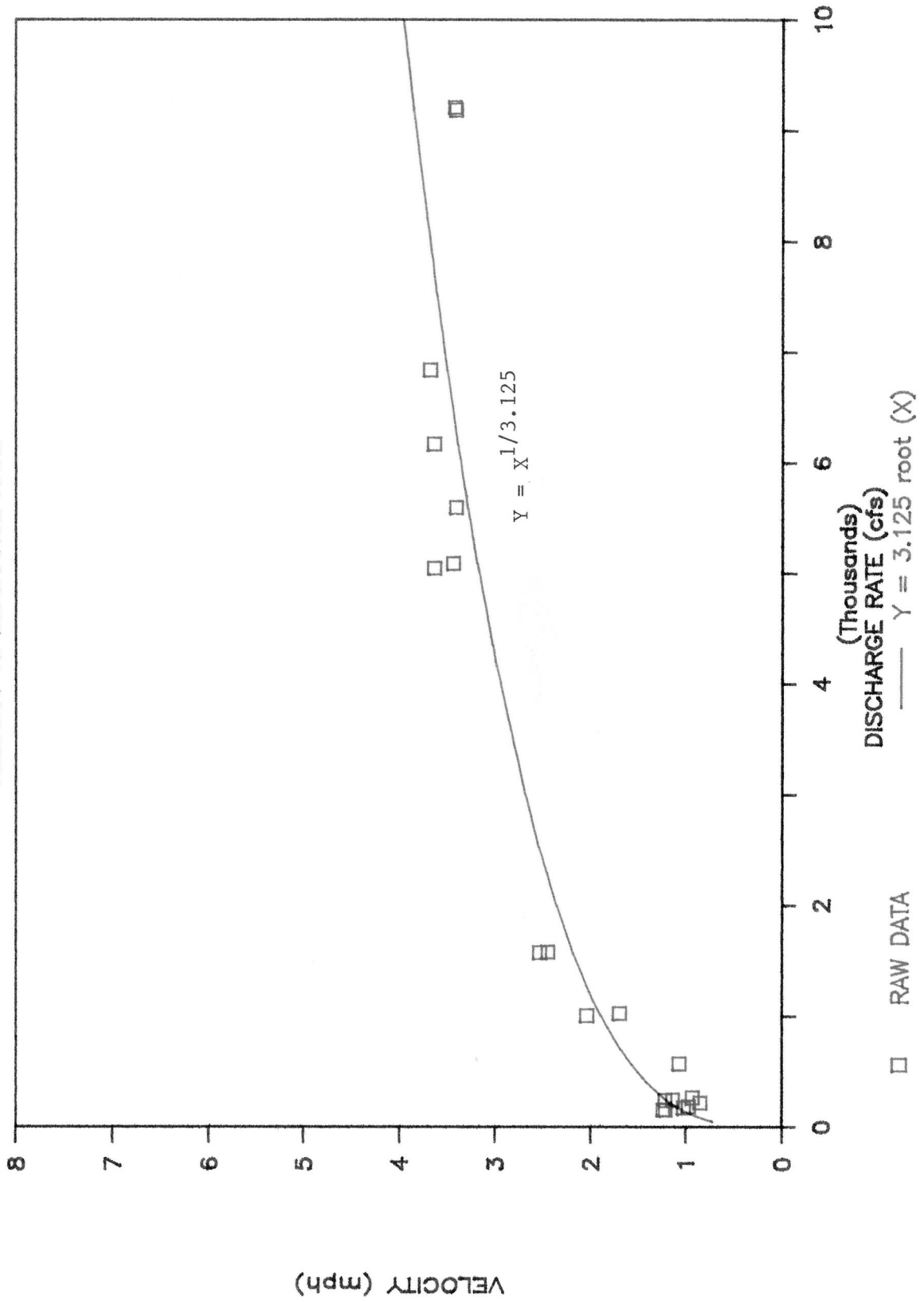
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Regression Output:  $0.0206 \times \ln X$

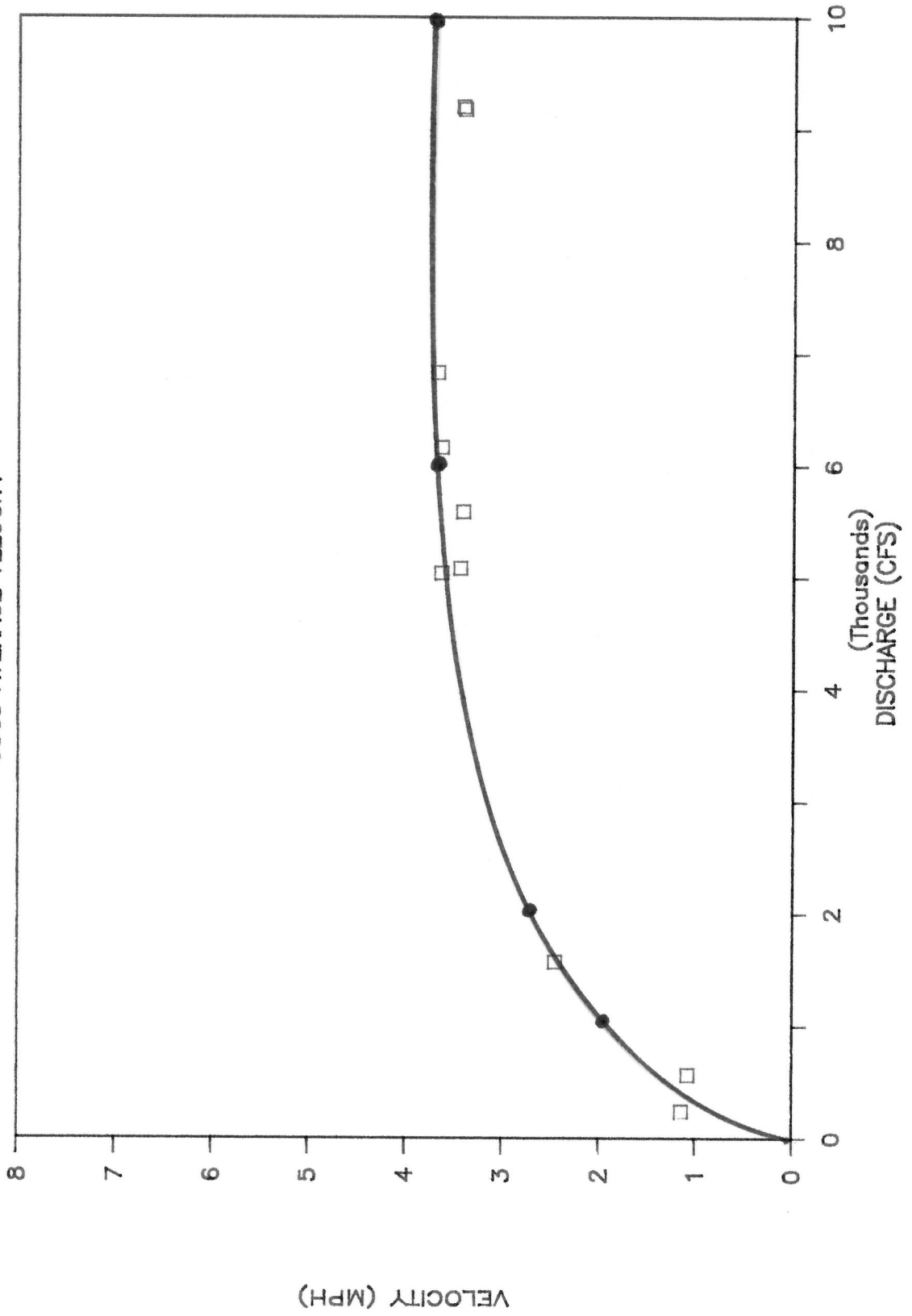
Std Err of Y Est	0.655488
R Squared	0.663799
No. of Observations	20
Degrees of Freedom	19
X Coefficient(s)	0.327249
Std Err of Coef.	0.020656

# HOPLAND

VELOCITY vs DISCHARGE RATE



HOPLAND  
USGS AVERAGE VELOCITY



FIT - BY - EYE



U.S.G.S. SPEEDS AT GAUGING STATIONS ON THE RUSSIAN RIVER

CLOVERDALE RAW DATA

DISCHARGE RATES (CFS):

\*\*\*\*\*SPEED\*\*\*\*\*

CLOVERDALE SUMMARY

DISCHG. SPEED

\*\*\*\*\*

152	180	188	240	249	282	465	1140	1350	1550	2530	12200
(FPS)	(FPS)	(FPS)	(FPS)	(FPS)	(FPS)	(FPS)	(FPS)	(FPS)	(FPS)	(FPS)	(FPS)
0.268	1.8	0.345	0.818	0.156	0.99	1.42	0.616	2	0.806	2.47	2.68
0.273	1.92	0.604	1.66	0.426	1.11	2.37	0.616	2.44	0.474	2.94	3.3
0.637	1.96	0.747	2.44	0.655	1.32	2.61	3.4	2.86	1.5	3.93	5.22
0.649	1.88	0.747	2.2	0.874	1.29	2.68	2.49	3.06	1.06	4.37	5.75
0.604	1.8	0.747	2.18	0.817	1.2	3.13	3.98	3.2	1.68	3.93	5.81
0.615	1.76	0.615	2.32	0.822	1.2	3.28	2.78	3.43	2.13	4.37	6
0.615	1.58	0.687	2.56	0.834	1.08	3.57	2.67	3.94	2.83	3.93	6.92
0.637	1.58	0.674	2.5	0.75	1.16	3.5	3	4.4	3.53	2.6	6.48
0.637	1.66	0.763	2.56	0.85	1.29	3.5	3	4.32	3.73	3.57	6.49
0.649	1.44	0.763	2.58	0.888	1.11	3.57	2.86	4.66	3.58	3.8	5.9
0.687	1.35	0.827	2.58	1.1	1.35	3.28	3	4.72	3.99	4.26	5.53
0.649	1.51	0.747	2.52	0.964	1.26	2.86	2.74	4.8	3.34	4.37	6.12
0.716	1.38	0.827	2.65	0.964	1.26	3.28	2.83	4.61	2.95	4.16	6.83
0.649	1.29	0.78	2.50	0.945	1.26	3.5	2.42	4.75	3.19	4.46	7.8
0.661	1.09	0.78	2.29	0.852	1.2	3.37	1.82	4.65	3.85	5.08	7.82
0.674	1.11	0.747	2.47	0.902	1.23	3.4	2.08	4.37	3.87	5.74	8.26
0.649	0.948	0.747	2.65	0.838	1.13	3.51	2.13	3.89	3.85	6.06	7.8
0.674	0.838	0.674	2.58	0.92	1.18	3.37	2.37	3.5	3.61	5.96	8.98
0.594	0.818	0.701	2.71	0.875	1.17	2.97	2.13	3.28	3.8	6	8.78
0.615	0.78	0.626	2.8	0.819	1.2	3.18	2.13	3.13	3.35	6	8.87
0.594	0.649	0.643	3.06	0.858	1.2	2.97	1.98	2.99	2.99	5.64	7.72
0.584	0.701	0.648	2.92	0.89	1.16	1.63	1.68	2.74	3.39	5.46	8.08
0.584	0.637	0.673	2.5	0.914	1.26	1.23	1.72	2.44	3.7	5.53	7.24
0.375	0.504	0.751	2.34	0.858	1.38		2.08	1.86	2.79	5.33	7.8
0.504	0.447	0.733	2.29	0.875	0.431	2.96	1.71	1.49	0.515	4.8	6.55
0.763	0.424	0.718	1.35	0.674				1.19		4.4	6.23
0.637	0.156	0.772		0.515	1.18		2.33	0.357	2.82	3.98	6.06
		0.687	2.39	0.141						3.43	5.32
0.60	1.19	0.752		0.165				3.30		2.4	7
										0.24	5.55
		0.71		0.76						0.43	2.5
										1.09	2.92
										4.06	
										3.02	6.38
										4.05	

DISCHG.	SPEED	
(CFS)	(FPS)	(MPH)
152	0.6	0.41
180	1.19	0.81
188	0.71	0.48
240	2.39	1.63
249	0.76	0.52
282	1.18	0.80
465	2.96	2.02
1140	2.33	1.59
1350	3.3	2.25
1550	2.82	1.92
2530	4.05	2.76
4160	5.26	3.59
5700	5.64	3.85
6810	5.97	4.07
7510	5.87	4.00
11200	6.12	4.17
12200	6.38	4.35
20500	7.4	5.05

Cloverdale - Cummiskey Station Rd. Gauge

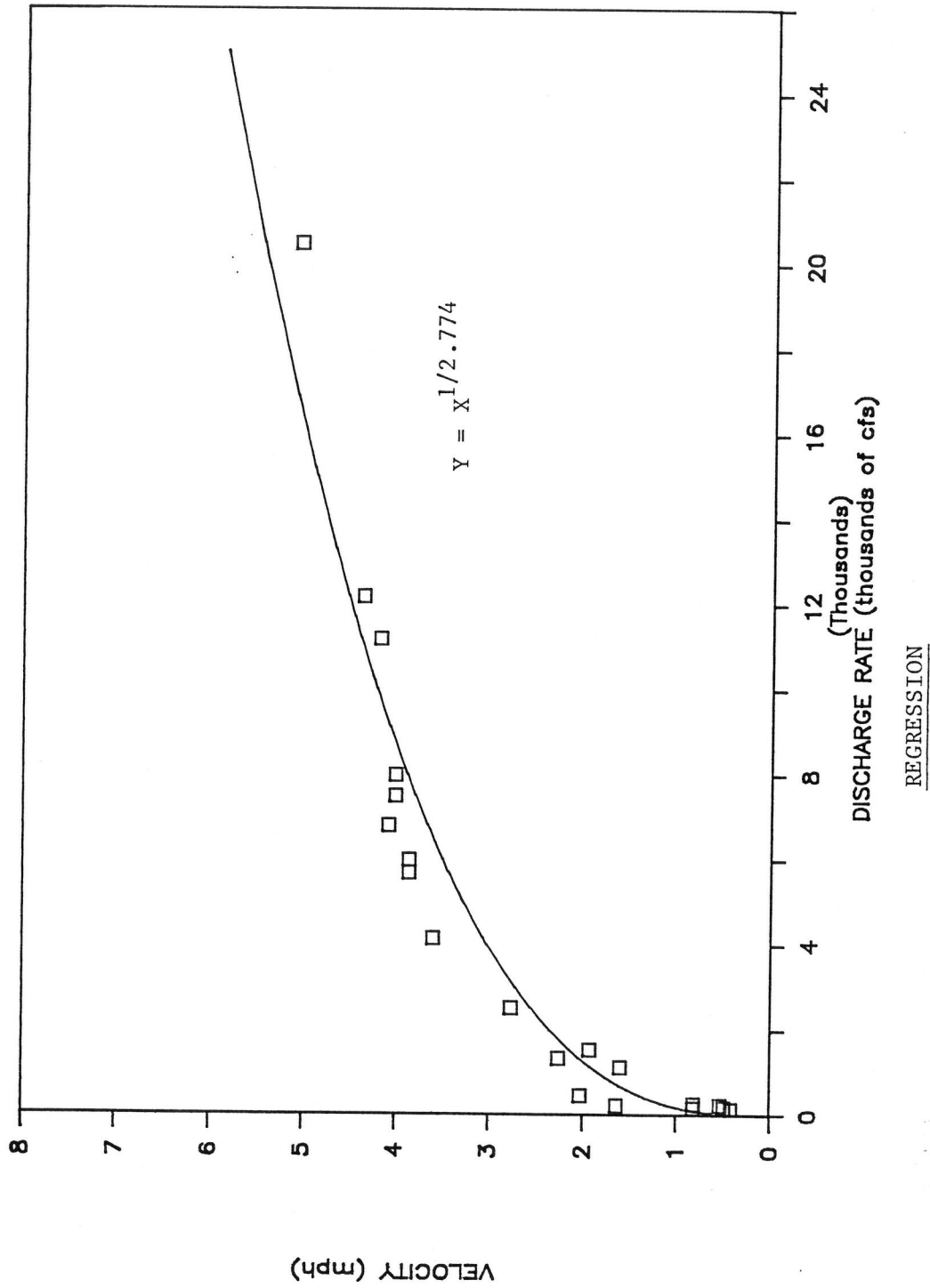
Q	Vel (mph)
152	0.41
180	0.81
188	0.48
240	1.63
249	0.52
282	0.80
465	2.02
1140	1.59
1350	2.25
1550	1.92
2530	2.76
4160	3.59
5700	3.85
6810	4.07
7510	4.00
11200	4.17
12200	4.35
20500	5.05

Selected Regression:  $Y = 0.1525 \times X^{(1/2.774)}$

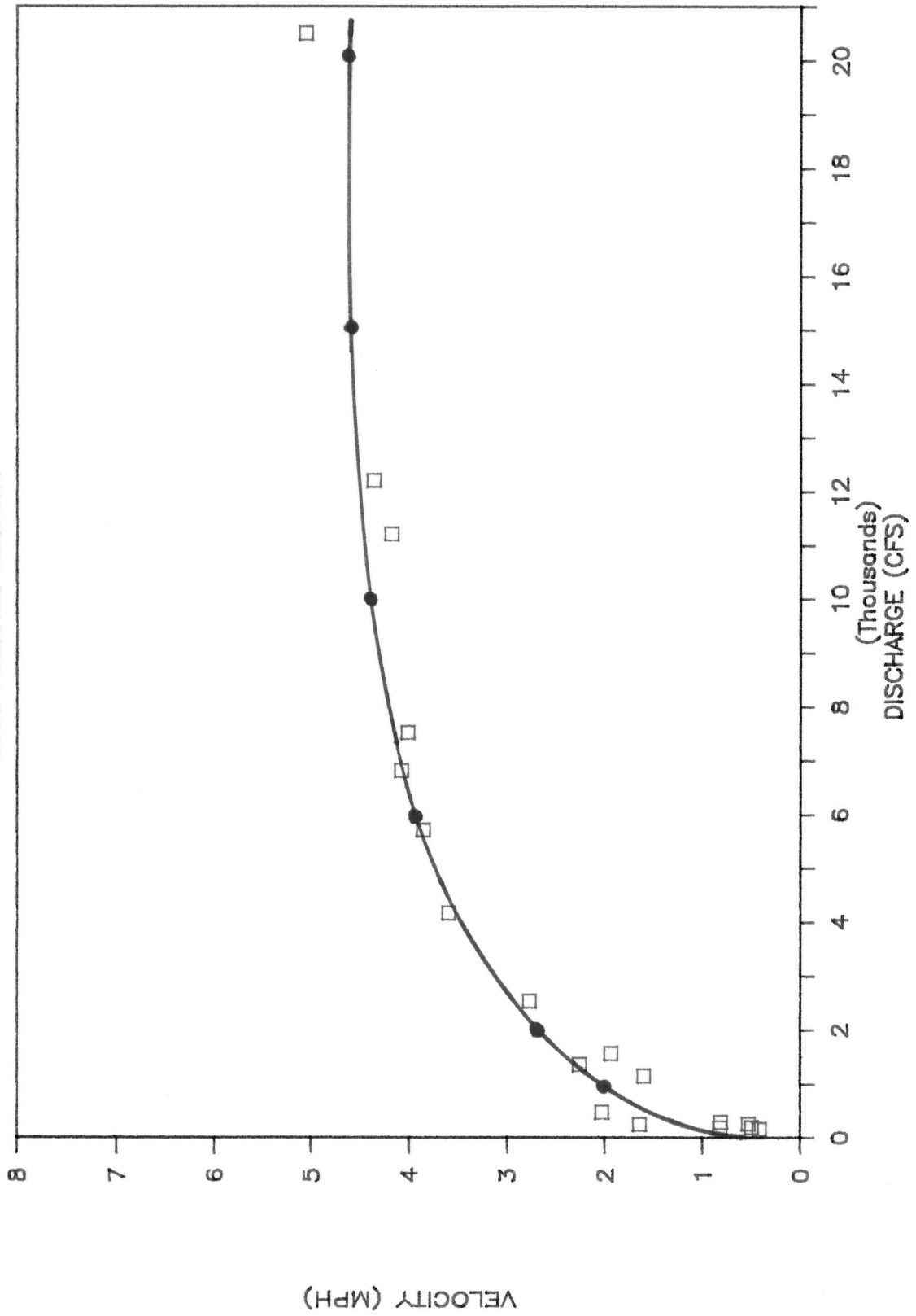
Std Err of Y Est            0.410703748  
R Squared                    0.929729209  
No. of Observations            18  
Degrees of Freedom            17  
X Coefficient            0.152490  
Std Err of Coef.            0.005168

Regression Output:  $Y = 0.3646 \times \ln X$   
Std Err of Y Est            0.984123602  
R Squared                    0.596524841  
No. of Observations            18  
Degrees of Freedom            17  
X Coefficient(s)            0.364570  
Std Err of Coef.            0.031084

# CLOVERDALE GAUGE (Cummiskey Stn.)



# CLOVERDALE USGS AVERAGE VELOCITY



FIT - BY - EYE

U.S.G.S. SPEEDS AT GAUGING STATIONS ON THE RUSSIAN RIVER

HEALDSBURG RAW DATA

DISCHARGE RATES (CFS):

296	417	1906	11665
*****SPEED*****			
(FPS)	(FPS)	(FPS)	(FPS)
0.347	1.96	0.828	0.85
0.494	2.74	0.81	2.44
0.661	2.99	1.58	4.35
0.643	3.13	1.58	5.51
0.734	3.28	1.7	6.96
0.766	3.31	1.46	7.43
0.727	3.28	2	7.03
0.71	2.92	2.17	6.79
0.62	2.99	2.16	7.23
0.692	3.06	2.51	7.74
0.657	2.99	2.4	7.14
0.702	2.8	2.54	7.2
0.819	2.92	2.22	6.92
0.827	2.83	2.65	7.98
0.944	2.86	2.56	7.23
0.978	2.52	2.48	7.42
0.867	2.18	2.25	6.94
0.91	2.32	2.32	7.66
0.874	2.1	2.1	7
0.79	1.92	1.48	7.07
0.752	1.35	1.24	6.22
0.701	1.03	0.848	5.86
0.626	1.11	1.01	4.8
0.637	0.99	1.07	2.24
0.604		0.928	
0.534	2.48	0.735	6.17
0.594		0.431	
0.552		0.359	
0.462			
		1.66	
0.70			

HEALDSBURG SUMMARY

DISCHG.	SPEED	
(CFS)	(FPS)	(MPH)
296	0.7	0.48
417	2.48	1.69
1906	1.66	1.13
9120	5.36	3.65
10200	5.2	3.55
11665	6.17	4.21
11700	6.16	4.20
13300	5.71	3.89
15200	6.5	4.43
16900	6.08	4.15
39900	9.28	6.33
41600	8.67	5.91
53100	10.49	7.15

Healdsburg Gauge

Q	Vel (mph)
296	0.48
417	1.69
1906	1.13
9120	3.65
10200	3.55
11665	4.21
11700	4.20
13300	3.89
15200	4.43
16900	4.15
39900	6.33
41600	5.91
53100	7.15

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 Selected Regression:  $Y = 0.0932 \times X^{(1/2.52)}$

Std Err of Y Est	0.390594
R Squared	0.959741
No. of Observations	13
Degrees of Freedom	12
X Coefficient(s)	0.093167
Std Err of Coef.	0.002339

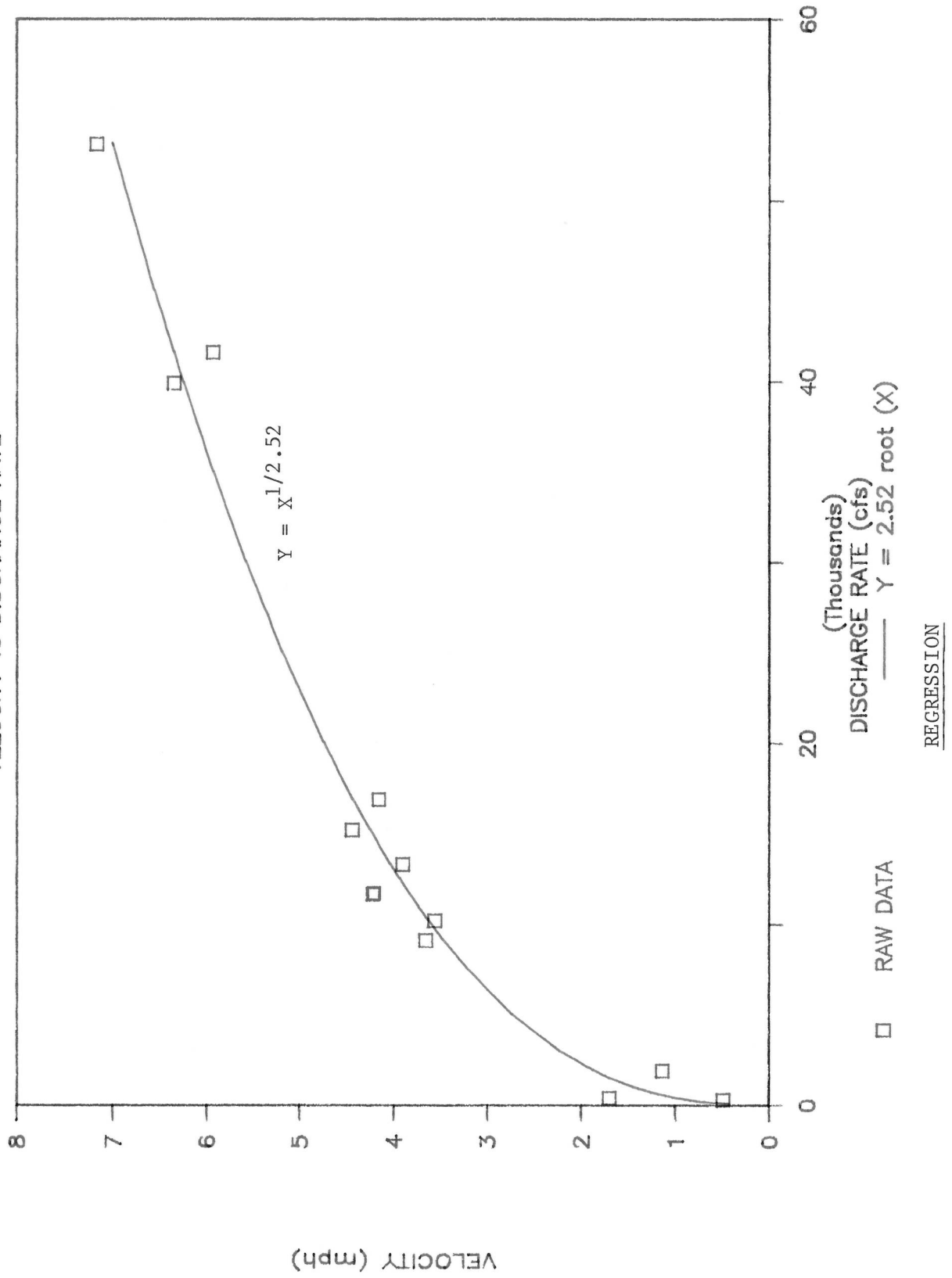
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Regression Output:  $Y = 0.4528 \times \ln X$

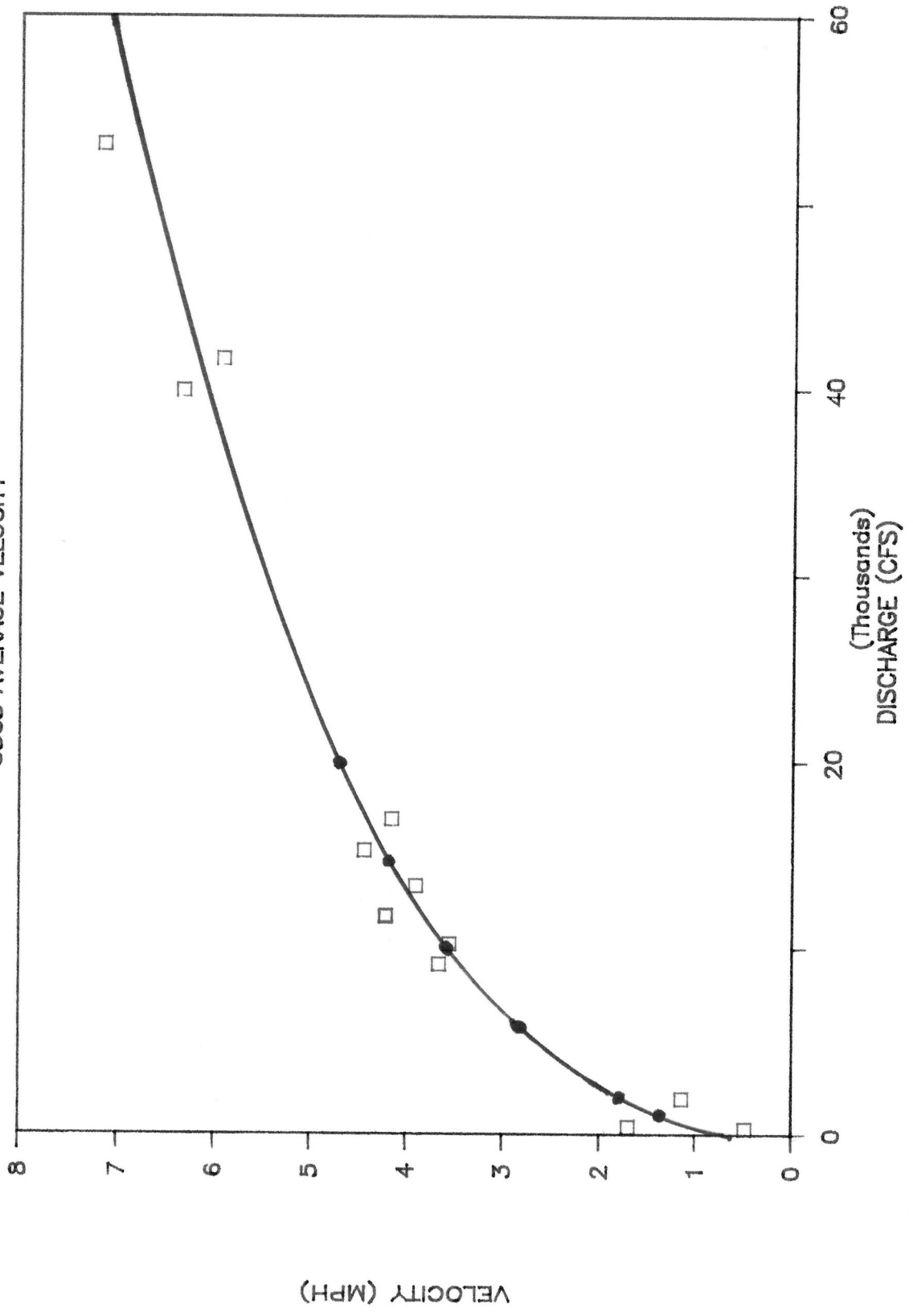
Std Err of Y Est	1.293674
R Squared	0.558371
No. of Observations	13
Degrees of Freedom	12
X Coefficient(s)	0.452786
Std Err of Coef.	0.039166

# HEALDSBURG

## VELOCITY vs DISCHARGE RATE



# HEALDSBURG USGS AVERAGE VELOCITY



FIT - BY - EYE



U.S.G.S. SPEEDS AT GAUGING STATIONS ON THE RUSSIAN RIVER

GUERNEVILLE RAW DATA

DISCHARGE RATES (CFS):

225.76	593.06	4143	11524	27825
*****SPEED*****				
(FPS)	(FPS)	(FPS)	(FPS)	(FPS)
0.843	0.892	0.426	0.239	1.03
2.37	1.38	1.33	2.17	4.44
2.48	2.1	2.05	4.32	4.04
3	2.74	2.41	4.32	4.72
3.1	3.21	2.63	4.4	4.91
2.61	3.54	2.26	4.73	3.38
2.68	3.5	2.86	4.87	6.34
2.61	4.12	2.73	4.46	7.52
3.21	4.66	2.74	4.56	6.81
2.92	4.36	2.93	4.46	6.53
2.86	4.05	3.23	4.65	6.72
3.13	4.08	2.98	4.56	7.07
2.92	3.5	2.75	4.37	6.9
3.5	4.51	2.57	4.46	7.08
3.21	4.16	2.47	3.92	7.06
3.21	4.33	2.32	3.86	6.76
2.74	3.76	2.29	3.46	6.57
2.68	4.22	2.08	2.94	6.04
2.92	3.85	2.25	3.06	6.11
2.74	3.68	1.5	2.61	6.15
2.39	3.1	1.68	2.12	5.23
1.51	3.37	1.23	1.68	5.22
0.341	3.06	0.41	1.03	4.17
	2.15	0.467	0.415	4.73
2.61	0.838			4.19
		2.11	3.40	2.34
	3.33			0.474
				5.28

GUERNEVILLE SUMMARY

DISCHG.	SPEED	
(CFS)	(FPS)	(MPH)
208 *	2.38	1.62
212 *	1.63	1.11
226	2.61	1.78
332 *	2.96	2.02
333 *	3.75	2.55
356 *	2.27	1.55
364 *	2.95	2.01
381 *	3.07	2.09
548 *	1.94	1.32
593	3.33	2.27
1090 *	1.02	0.70
1670 *	1.35	0.92
2030 *	1.50	1.02
2440 *	1.70	1.16
4140 *	1.62	1.10
4143	2.11	1.44
8300	3.11	2.12
10720	3.37	2.30
11524	3.4	2.32
13600	3.76	2.56
18400	4.1	2.80
19700	3.98	2.71
20000	4.94	3.37
25900	4.78	3.26
26700	4.73	3.23
27800	5.26	3.59
27825	5.28	3.60
36400	5.1	3.48
38600	5.21	3.55
47800	5.46	3.72
55000	5.57	3.80

\* V = Discharge/Area

Guerneville - Hacienda Bridge Gauge

Q	Vel (mph)
548	1.32
593	2.27
1090	0.70
1670	0.92
2030	1.02
2440	1.16
4140	1.10
4143	1.44
8300	2.12
10720	2.30
11524	2.32
13600	2.56
18400	2.80
19700	2.71
20000	3.37
25900	3.26
26700	3.23
27800	3.59
27825	3.60
36400	3.48
38600	3.55
47800	3.72
55000	3.80

-----  
 Selected Regression:  $Y = 0.1064 \times X^{(1/3)}$

Std Err of Y Est	0.406647
R Squared	0.848758
No. of Observations	23
Degrees of Freedom	22
X Coefficient(s)	0.106417
Std Err of Coef.	0.003438

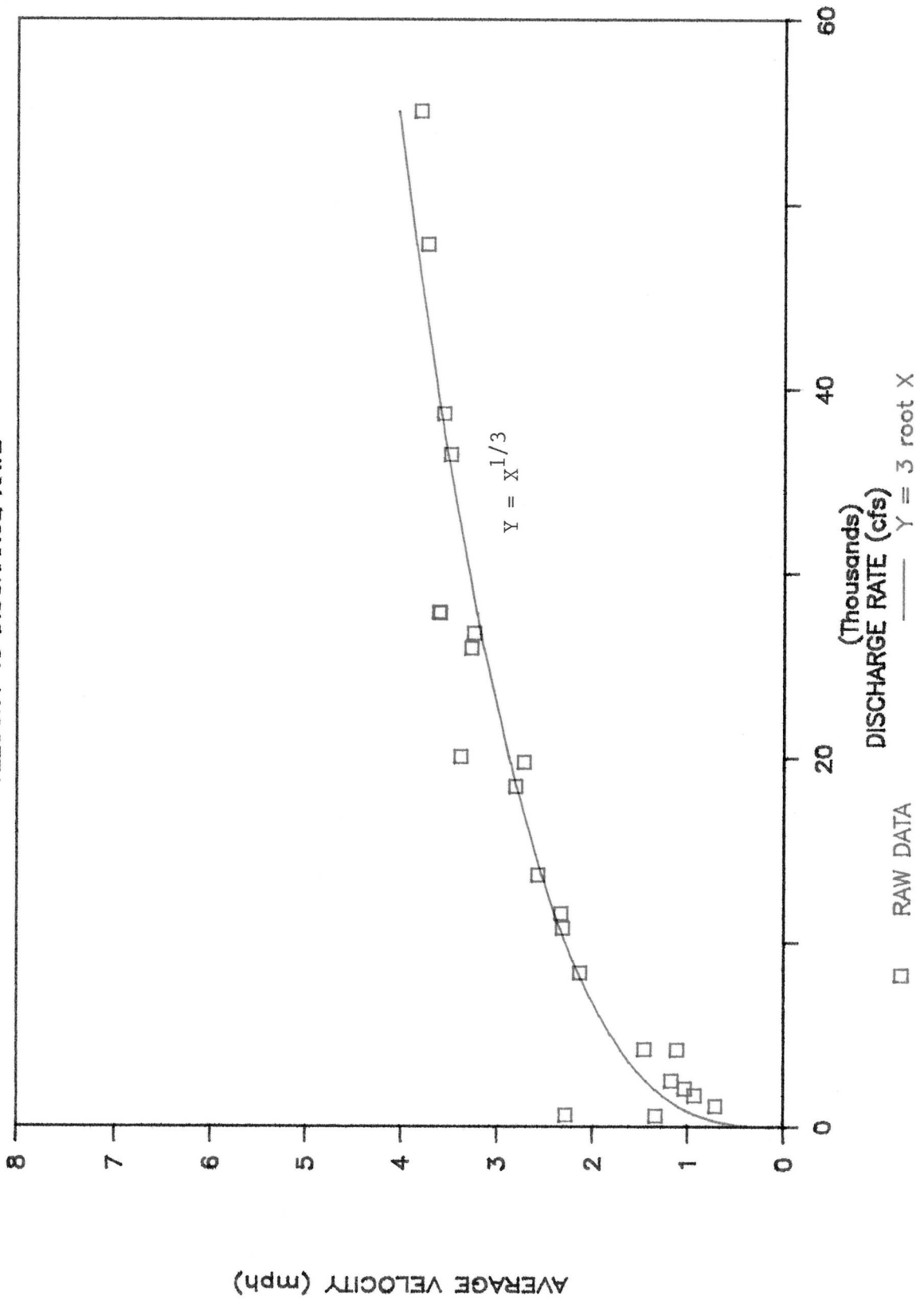
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Regression Output:  $Y = 0.2774 \times \ln X$

Std Err of Y Est	0.730089
R Squared	0.512487
No. of Observations	23
Degrees of Freedom	22
X Coefficient(s)	0.277401
Std Err of Coef.	0.016517

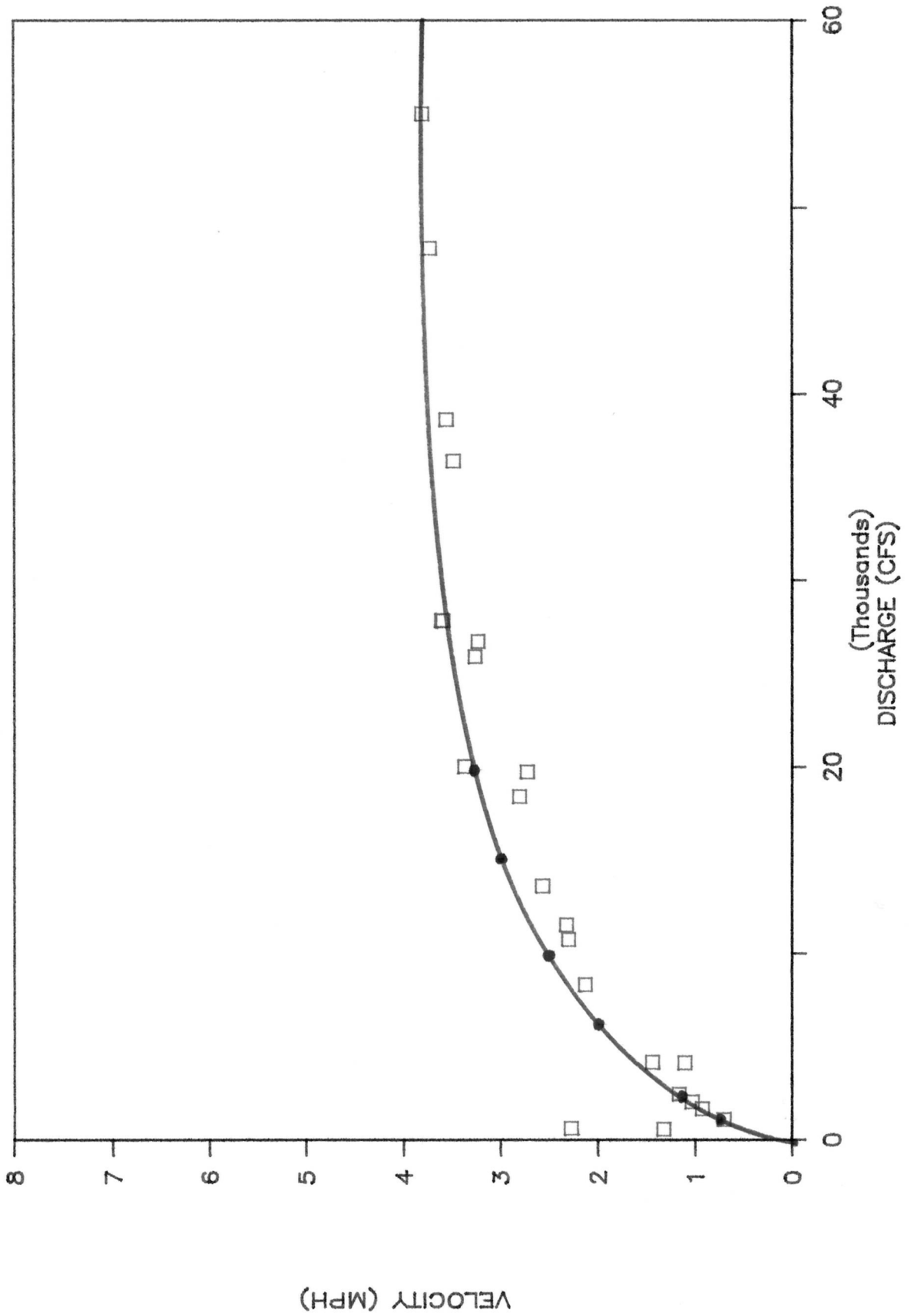
# GUERNEVILLE

## VELOCITY vs DISCHARGE RATE



# GUERNEVILLE

USGS AVERAGE VELOCITY



FIT - BY - EYE

SPEEDS PER REGRESSION CURVE

Discharge (cfs)	Hopld (mph)	Clovd1. (mph)	Healds (mph)	Guerne. (mph)
400	1.42	1.32	1.00	0.78
1000	1.90	1.84	1.44	1.06
2000	2.37	2.36	1.90	1.34
4000	2.96	3.03	2.50	1.69
6000	3.37	3.51	2.94	1.93
8000	3.69	3.89	3.30	2.13
10000	3.97	4.22	3.60	2.29
15000	3.97	4.88	4.23	2.62
20000	3.97	5.42	4.74	2.89
40000	3.97	6.95	6.24	3.64

SPEEDS AT DISCHARGE RATE FOR FORMALIN SPILL

Discharge (cfs)	Hopld (mph)	Clovd1. (mph)	Healds (mph)	Guerne. (mph)
1200	2.01			
1700		2.23		
2000			1.90	
3000				1.53

FORMULAE USED FOR COMPUTER CALCULATED SPEEDS:

Hopland - (.208182 \* exponent (ln (discharge)/3.125))  
 Cloverdale - (0.15249 \* exponent (ln (discharge)/2.774))  
 Healdsburg - (0.093167 \* exponent (ln (discharge)/2.52))  
 Guerneville - (0.106417 \* exponent (ln (discharge)/3))

NOTE: HOPLAND VELOCITY HELD CONSTANT FOR DISCHARGE RATE OF 10000 CFS.