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Acknowledgement

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ABSTRACT

The variation of solutes and particulate material with discharge during summer storm events was studied for the summer 1990 in the East Branch of Wappinger Creek, New York. The concentration of hydrogen ion, total suspended solid, total phosphorus, and particulate organic matter increased as discharge increased, and displayed clockwise hysteresis with rising and falling discharge. Ca^{++}, Mg^{++}, Na^{+}, Cl^{-}, and dissolved oxygen (DO) showed a negative relation with discharge. Concentration of SiO_2 always increased during a storm discharge. After an initial increase, K^{+} and NO_3^{-} decreased with increasing discharge following thunder storms. The effect of different types of rainstorms on elemental dynamics was studied. The impact of the length of time between storm events on the changes in ion concentration was also discussed.

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1. Introduction

Why do we study the effects of storm events on the elemental dynamics of streams? J. Meyer said in her article: this is "part of the larger group of questions on the impact of disturbance on streams. Storms may serve as an element subsidy by mobilizing previously unavailable nutrient sources, and nutrients taken up during short periods of elevated concentration may support growth over several days" (J. Meyer, 1988). However, some questions, such as the distinction between a disturbance and subsidy, and the different effects between low intensity and long duration, and high intensity and short duration storms, are unclear because of the lack of data.

The purpose of this paper is to provide basic information about elemental dynamics of the East Branch of Wappinger Creek (EBWC) during summer storm events. The changes in the transport of element concentration with different stream discharges were studied. Effects of different types of rainstorms, and length of time between storm events are also discussed.

2. Site Description and Methods

This study was done at the Institute of Ecosystem Studies (IES), The New York Botanical Garden, Millbrook, New York. Stream water samples were collected from the Fern Glen site in the East Branch of Wappinger Creek(41°47' N, 73°44' W) (Figure 1). The area of EBWC watershed is 40 square kilometers. The area within the EBWC watershed which is above the sampling station at Fern Glen is 20 square kilometers. This is an area covered by old growth conifers and broad leafed trees, as well as some farmland. The stream is dominated by riffles and pools with a gravel streambed. The local bedrock consists of shale and graywacke. "The average amount of annual precipitation is 40 inches (or 101.6cm). Precipitation is usually well distributed throughout the year. July is the month of highest average rainfall" (G. Ayer and F. Pauszek, 1968). The Millbrook Sewage Treatment Plant is about 2 miles upstream from the sampling station. The design flow of the plant is 150,000 gallons per day (or 567.81 cubic meter per day). The discharge rate is automatically controlled, so no extra wastewater is discharged during a storm event.

One hundred and six stream water samples from seven summer storm events (including four thunder storms, one long duration rain, and two very short duration rains) were collected during May - July, 1990. Samples were taken in new 500-ml plastic bottles that were rinsed three times with stream water prior to collecting a water sample. Samples were taken once an hour before the peak discharge. After the

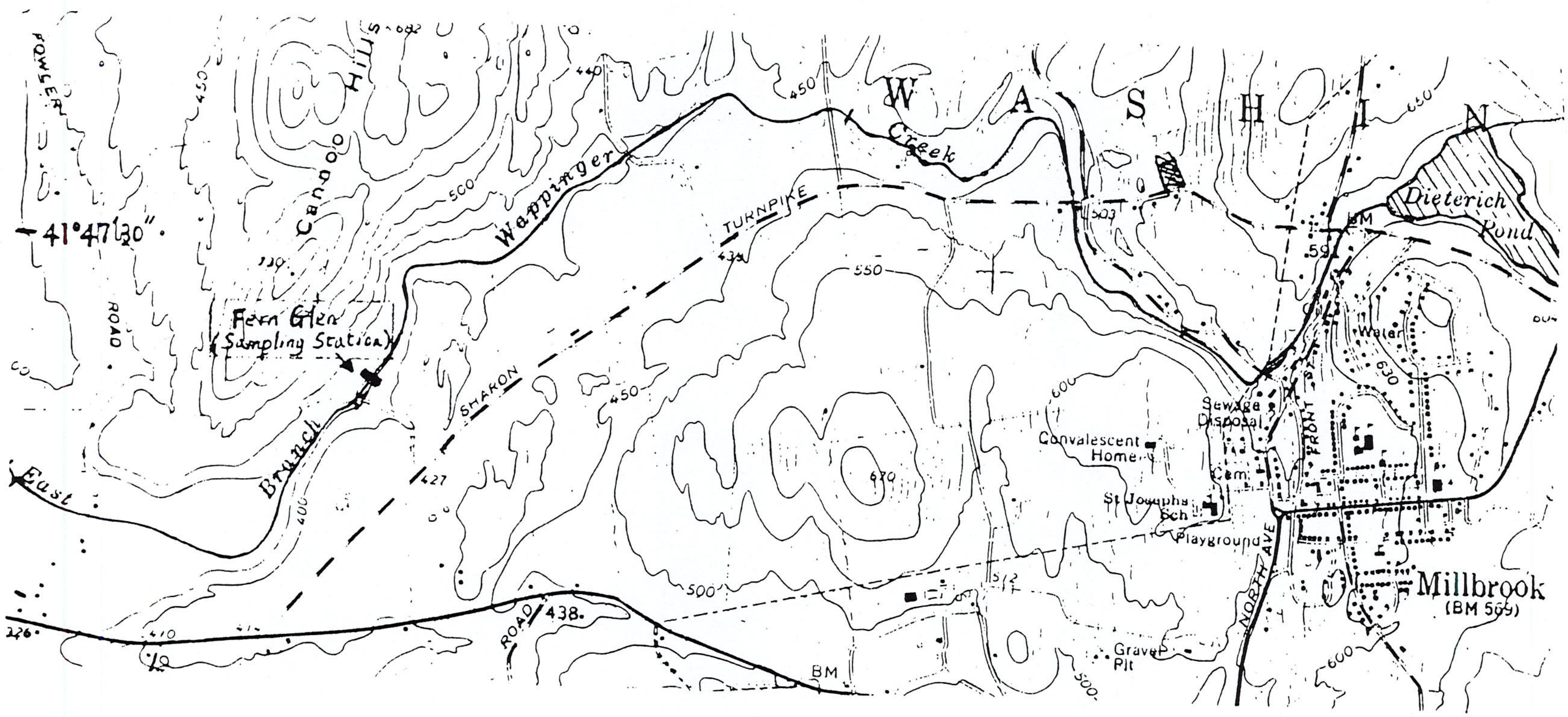


Figure 1. The EBWC and location of sampling station

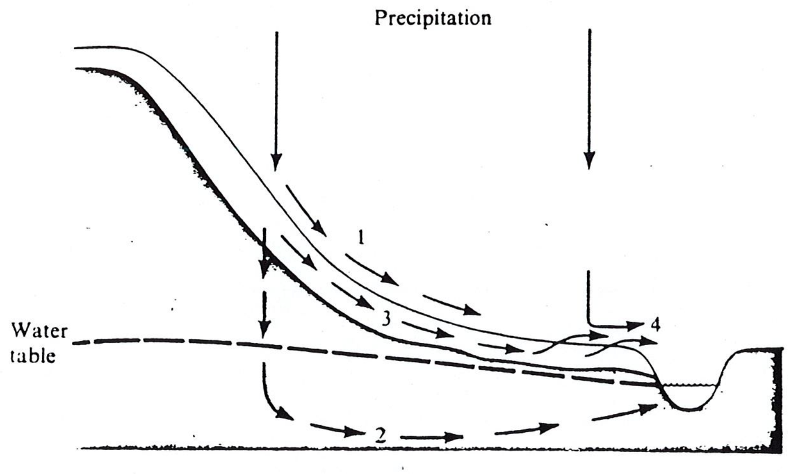


Figure 2 (a)
Possible paths of water moving downhill.
Path 1: Surface flow
Path 2: Groundwater
Path 3: Subsurface water
Path 4: Saturated overland flow

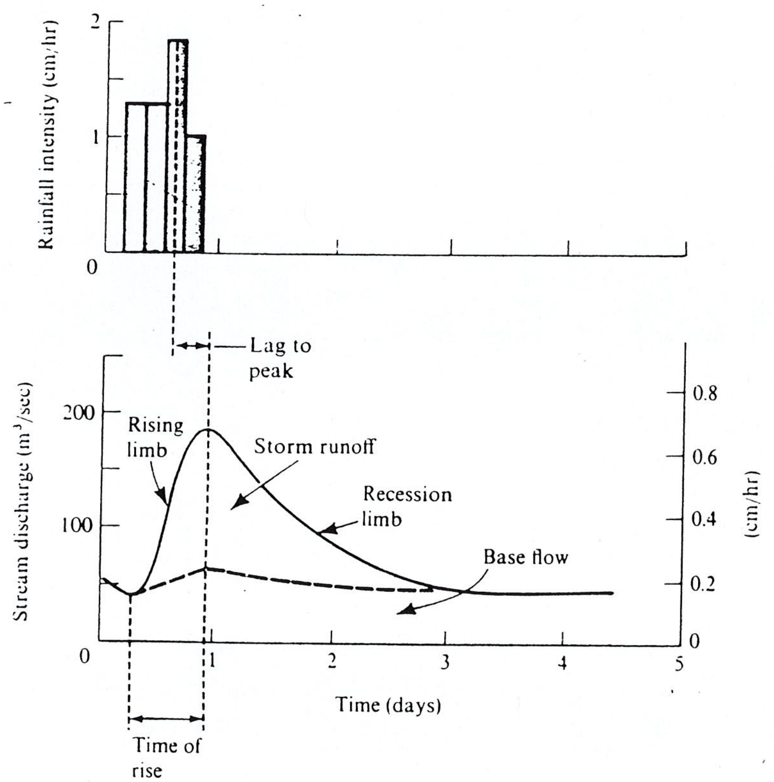


Figure 2 (b). Hydrograph of streamflow in response to a rainstorm (source: T. Dunne and L. Leopold, 1978) peak, samples were taken at a longer interval (two to several hours). Stream velocity, depth of the river at three points along the section, concentration of dissolved oxygen (DO), and water temperature were measured in the field when samples were taken. Total suspended solid (TSS), particulate organic matter (POM), pH, concentration of Cl^-, NO_3^-, $SO_4^=$, Mg^{++}, Ca^{++}, K^+, Na^+, SiO_2, total phosphorus (TP), ortho phosphorus (Ortho-P), Mn, and Fe were analyzed in inorganic laboratory of the IES. The facilities used for water sample analysis are listed as follows:

Facility Name	Elements Measured
Inductive Coupled Plasma (ICP)/6000	Ca^{++}, Mg^{++}, SiO_2, Mn, and Fe
Atomic Absorption Spectrophotometer (AAS)/2380	Na^+ and K^+
Ion Chromatograph (IC)	Cl^-, NO_3^-, and $SO_4^=$
pH Meter Model 610A	pH
UV-160 Recording Spectrophotometer	TP
Auto Analyzer (AA)	Ortho-P
Glass microfiber filters (2.4cm)	TSS (combusted at 70°C, 20-24 hours); POM (combusted at 450°C, 4 hours)

3. Results and Discussion

There are two main sources carrying chemical ions in a stream during storm events: stormflow (including surface flow, subsurface flow, and saturation overland flow) and baseflow (Figure 2).

During the summer storm season of 1990, seven storms were studied. The relative ranges in magnitude of chemical concentration of stream water, the average depth of the river and flow rate of the EBWC are showed in Table 1.

(A) Changes in Concentration of Ions and Flow Rate during Storm Events

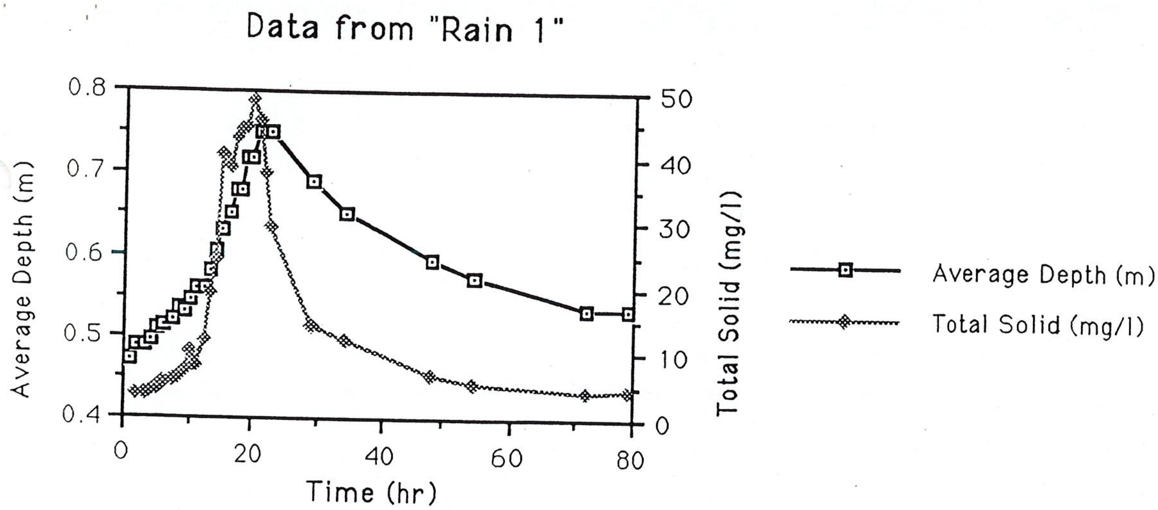
Although different types of rainstorms have different effects on elemental dynamics, some common characteristics for different rains exist:

(1) The concentration of TP, Ortho-P, and TSS increased with increasing discharge. During all storm events the peak in TP, TSS, and Ortho-P concentration occurs before the peak in discharge. Some typical examples are given in Figure 3. This phenomenon is the same as the conclusion in many previous studies. "The increases in TSS and TP are a consequence of increased ability to erode and to keep particulate matter suspended at higher flows" (J. Meyer, 1988). "Ortho-P may be applied to agricultural or residential cultivated land as fertilizer, and may be carried into surface water with storm runoff" (Clesceri et al, 1989). "Rainfall itself rather than increasing

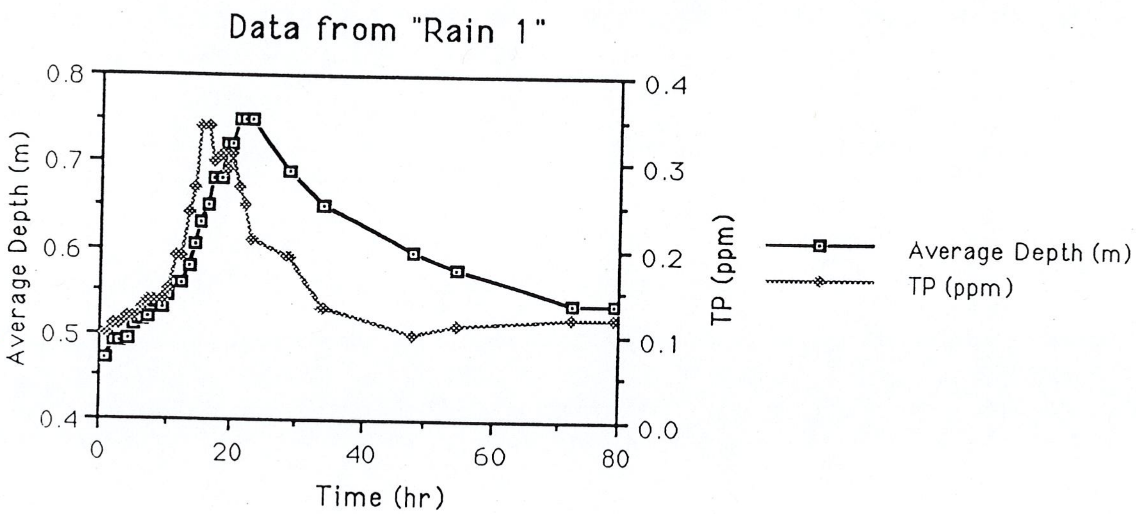
Table 1. Ranges in concentration of ion, average depth and flow rate of EBWC for the seven storms sampled from May to July, 1990

Date of Rain	5/29 - 5/30	6/9	6/18	6/29	7/20	7/22	7/23
Type of Rain	Long Duration Low Intensity	Thunder Storm	Thunder Storm	Thunder Storm	Short Duration Low Intensity	Short Duration Low Intensity	Thunder Storm
# of Samples	29	13	23	16	5	4	16
Range in Average Water Depth (cm)	47 - 75	47 - 62	44 -54	42 - 59	37 -38.5	37.5 - 39	39 - 43
Range in Flow Rate (m^3/s)*	0.96 - >3	0.76 - 1.30	0.54 - 1.49		0.25 - 0.29	0.27 - 0.29	0.26 - 0.40
Cl^-(ppm)	13.9 - 17.5	15.1 - 17.9	15.3 - 24.6	13.8 - 18.2	17.6 - 17.8	17.3 - 17.5	16.6 - 19.0
NO_3^- (ppm)	1.59 - 2.31	1.95 - 2.63	2.26 - 4.88	1.66 - 6.34	2.88 - 3.57	2.59 - 2.89	1.90 - 3.57
SO_4 (ppm)	11.0 -13.7	12.1 - 13.3	11.6 - 13.6	11.3 - 14.5	13.2 - 13.4	12.7 - 12.8	12.1 - 13.4
TSS (ppm)	3.44 - 48.6	3.31 - 39.1	4.20 - 62.1	2.55 - 127.4	2.30 - 3.02	1.40 - 3.76	0.48 - 6.48
TP (ppm)	0.10 - 0.34	0.13 - 0.43	0.18 - 0.54	0.13 - 0.69	0.26 - 0.27		
O-P (ppm)	0.07 - 0.15	0.07 - 0.11	0.08 - 0.17	0.13 - 0.24	0.25 - 0.27		
K^+(ppm)	0.68 - 0.85	0.78 - 0.91	0.85 - 1.12	0.78 - 1.33	1.00 - 1.01	0.94 - 0.97	0.75 - 0.96
Na^+(ppm)	7.60 - 9.20	8.39 - 9.73	9.10 - 14.6	8.32 - 10.8	10.7 - 10.8	10.5 - 10.6	10.1 - 11.4
Ca^{++}(ppm)	22.6 - 30.3	25.1 - 34.0	28.1 - 34.8	20.7 - 34.4	34.9 - 35.7	34.9 - 35.8	32.9 - 39.3
Mg^{++}(ppm)	6.31 - 7.73	6.74 - 8.74	7.71 - 9.39	5.23 - 9.69	9.42 - 9.99	9.11 - 9.95	8.82 - 10.2
POM (%)	21 - 82	16 - 47	10 - 27	12 - 32	16 - 27	21 - 29	<1 - 19
POM (ppm)	0.94 - 18.8	1.55 - 7.41	0.44 - 10.8	0.57 - 24.9	0.48 - 0.68	0.31 - 0.98	<0.1 - 0.80
pH	7.79 - 8.05	8.03 - 8.13	8.00 - 8.15	7.73 - 8.15	8.16 - 8.33	8.24 - 8.40	8.13 - 8.39
SiO_2 (ppm)	2.25 - 3.72	3.01 - 3.80	3.55 - 4.45	4.18 - 5.41	4.59 - 4.78	4.66 - 4.84	4.76 - 5.70
T°C	10.5 - 13.5	15.8 - 17.4	19.2 - 22.0	17.8 - 19.0			
DO (ppm)	9.0 - 10.0	9.4 - 10.0	8.7 - 14.2	8.8 - 9.6			

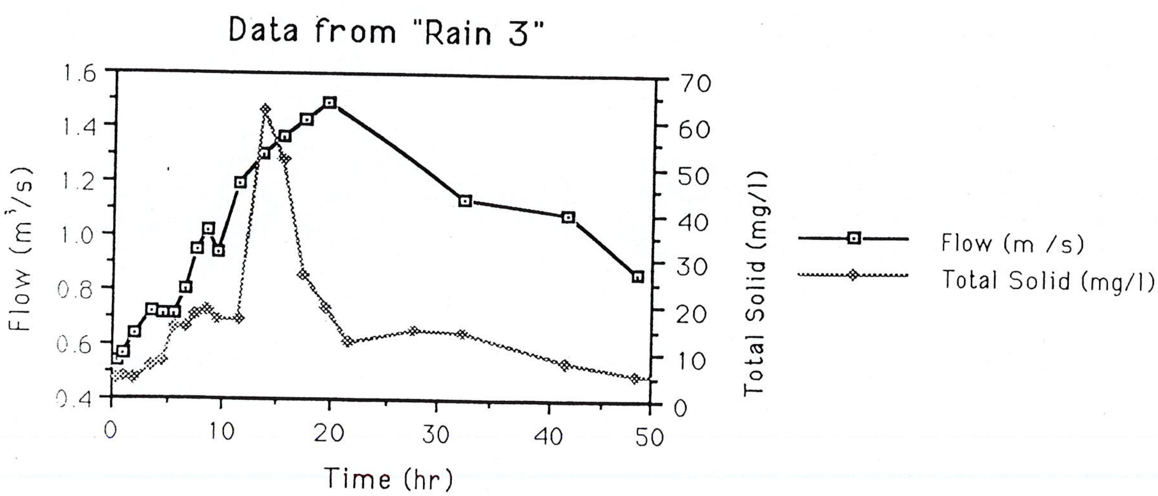
* Because the flow meter did not work well sometimes, some data are missing.



(a)



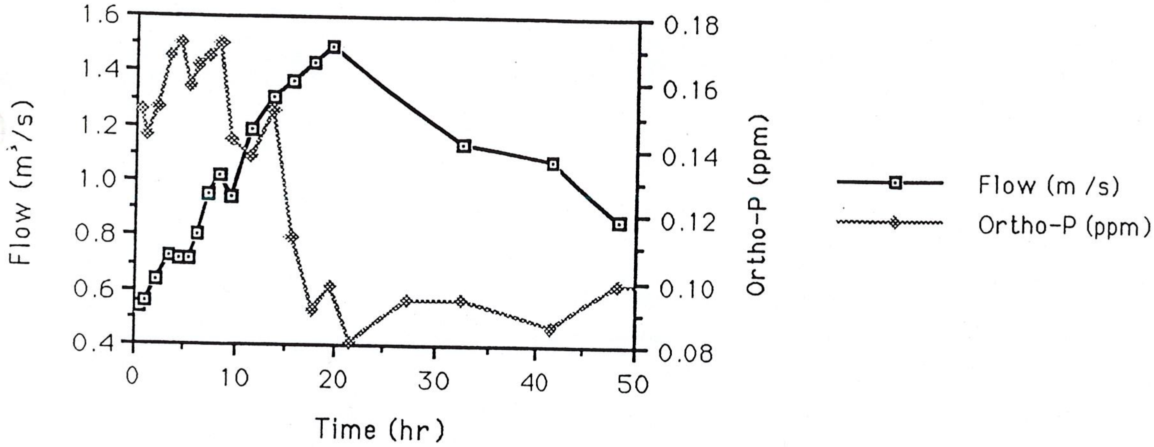
(b)



(c)

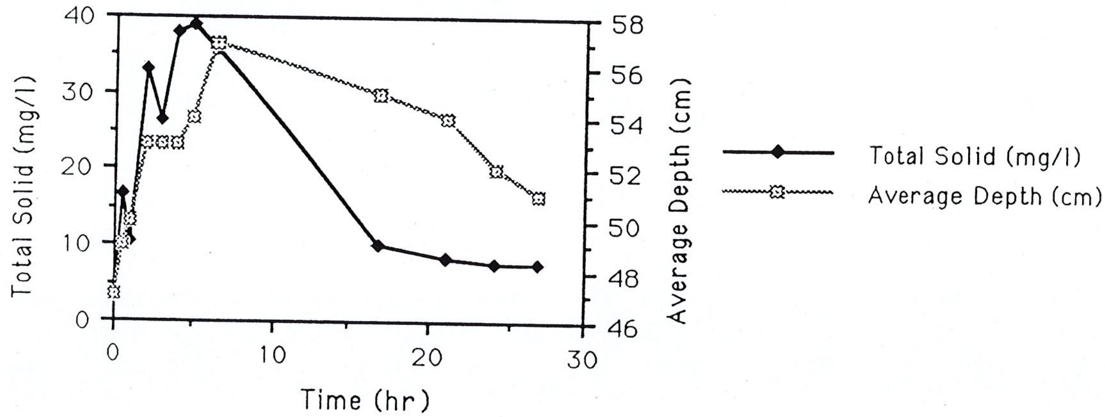
Figure 3. (a), (b), (c).

Data from "Rain 3"



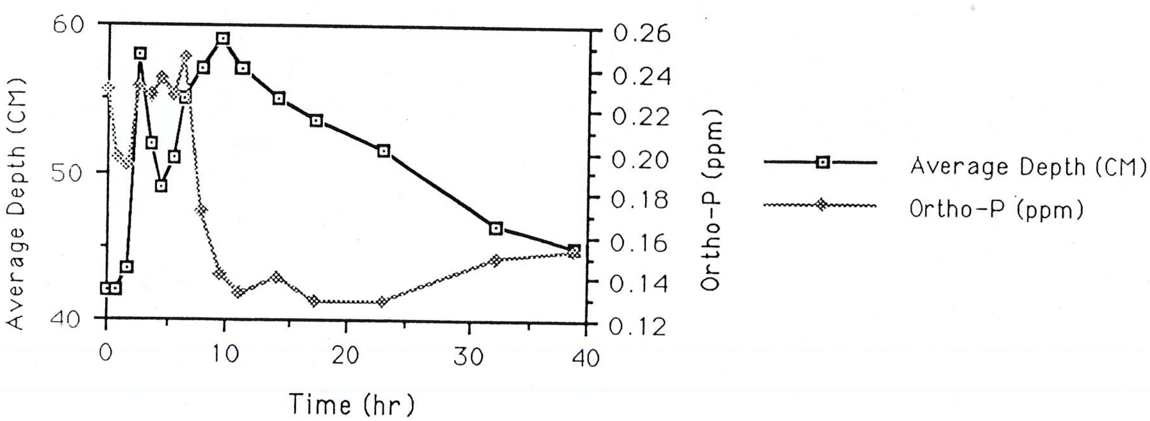
(d)

Data from "Rain 2"



(e)

Data from "Rain4"



(f)

Figure 3 (d), (e), (f)

flow appeared to be responsible for this early peak" (Bilby and Likens, 1979).

TSS in the EBWC during storm events might come from surface flow and bed sedimentation. Bed sedimentation seems to contribute substantially to TSS in the EBWC during a heavy storm, although the accurate proportion between TSS from bed sedimentation and from surface flow is unclear.

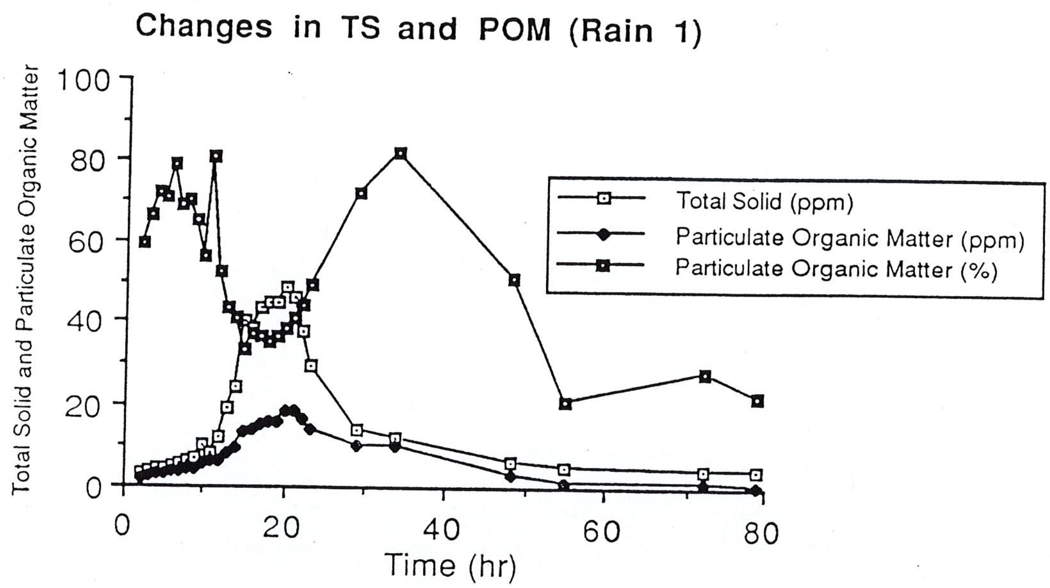
(2) The concentration of hydrogen ions increased when flow rate increased. That is, the curve of pH has a "valley" during a storm. This might be due to the increased loading of hydrogen ions from precipitation. The maximum range of changes in pH in EBWC during the summer of 1990 was 7.73 - 8.15, which occurred during Rain 4 that was a severe thunder storm.

(3) The concentration of Mg^{++}, Ca^{++} and Na^{+} decreases as flow rate increases, and increases as flow rate decreases with minor fluctuations. Also during any storm the "valley" in Mg^{++}, Ca^{++} and Na^{+} occurs before the peak in discharge. From Figure 2 we can see that the main sources carrying chemical ions into a river during a rainstorm are stormflow and baseflow. The concentration of Mg^{++}, Ca^{++}, and Na^{+} is much lower in precipitation than in groundwater. Therefore, the concentration of these ions in stormflow reflects the quality of precipitation, and the concentration in baseflow reflects the concentration level of groundwater. Therefore, elemental dynamics for a river during a storm event depends upon the contribution of

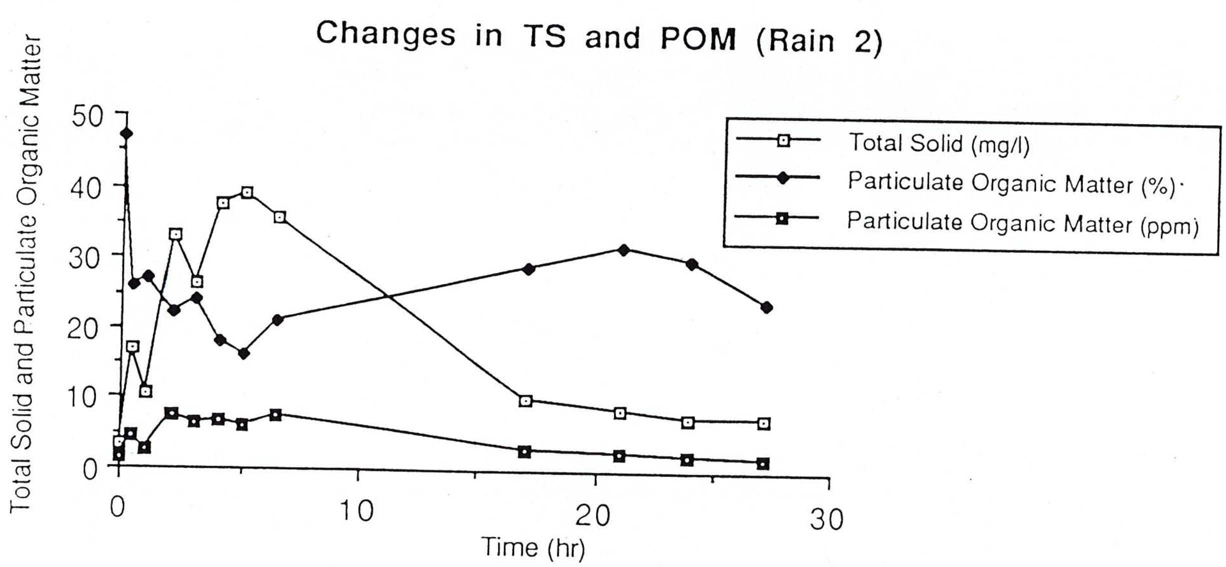
stormflow and baseflow. Figure 2 (b) indicates that the ratio (stormflow/baseflow) increases before the peak of discharge, and decreases after the peak. As a result, the concentration of Ca^{++}, Mg^{++}, and Na^{+} is diluted before the peak in discharge, and increases after the peak. However, it is difficult to use Figure 2 (b) to explain the fact that the "valley" in concentration occurs before the peak in discharge. Some modification should be made to Figure 2 (b): the lag between the highest intensity of rainfall and the peak of stormflow, and the peak of baseflow should be different, or the curve of baseflow and stormflow should not be a straight line. Further research is needed to answer these questions.

(4) Changes in TSS, POM (%) and POM (ppm) are showed in Figure 4. It is clear that POM (ppm) increases with the increase of TSS during a rainstorm, while POM (%) decreases with the increase of TSS. The "valley" of POM (%) is corresponding to the peak of TSS. This is because the increasing rate of non-organic suspended solid (such as fine sand) from the stream bottom, banks and river basin during a rain is greater than the increasing rate of organic matter from decomposed plant and animal products. After the end of a storm, POM (%) increases because sand and dirt begin to sediment due to the decreasing velocity of the river flow.

(5) The concentration of TSS, TP, Ortho-P, and hydrogen ion is hysteretic during storms, i.e. higher during the rising limb of the storm hydrograph than during the falling limb. Figure 5 gives some typical examples.

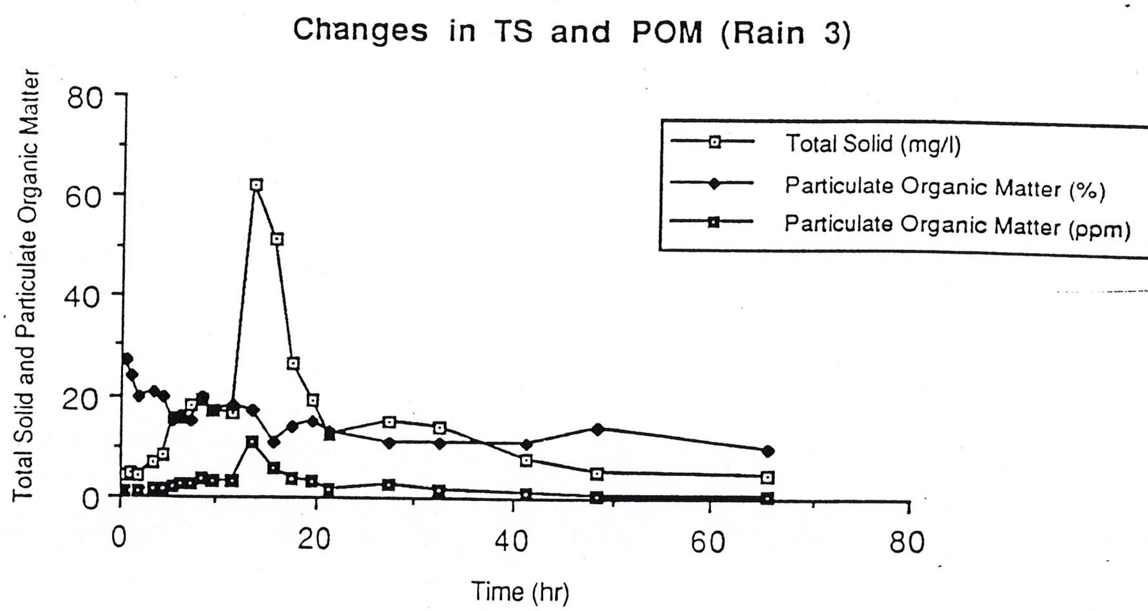


(a)

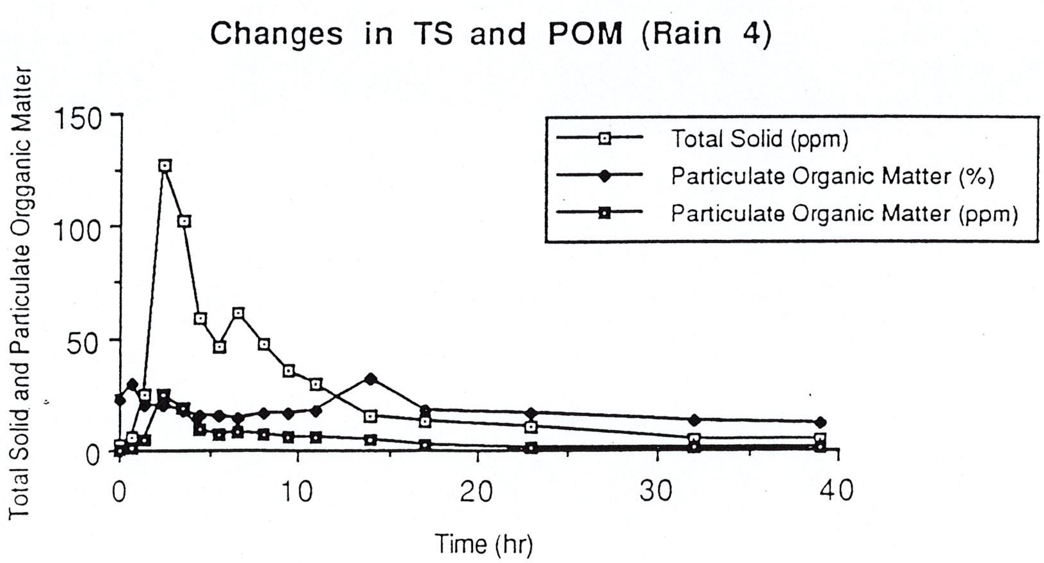


(b)

Figure 4 (a), (b)

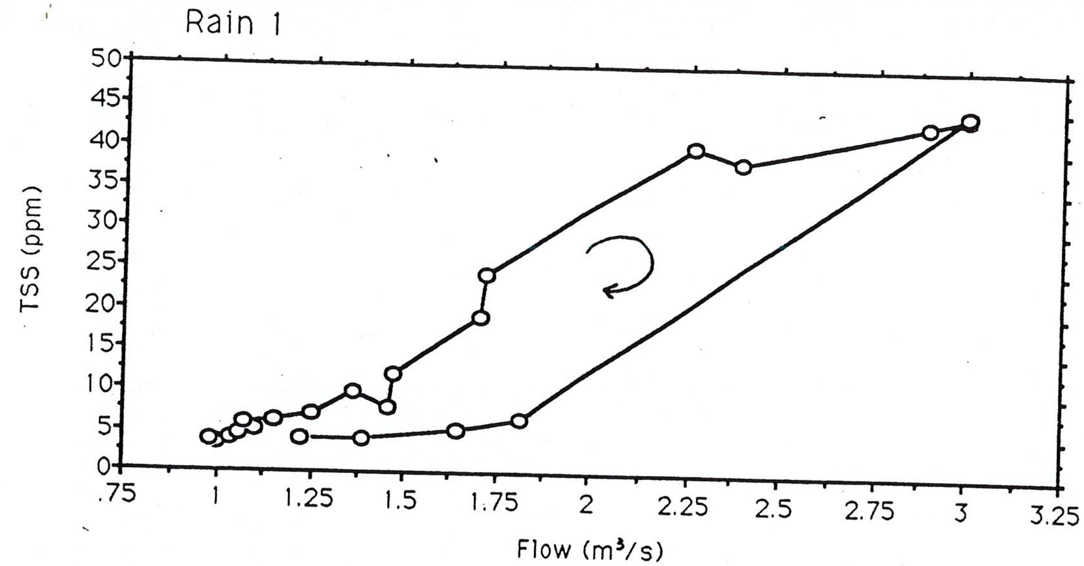


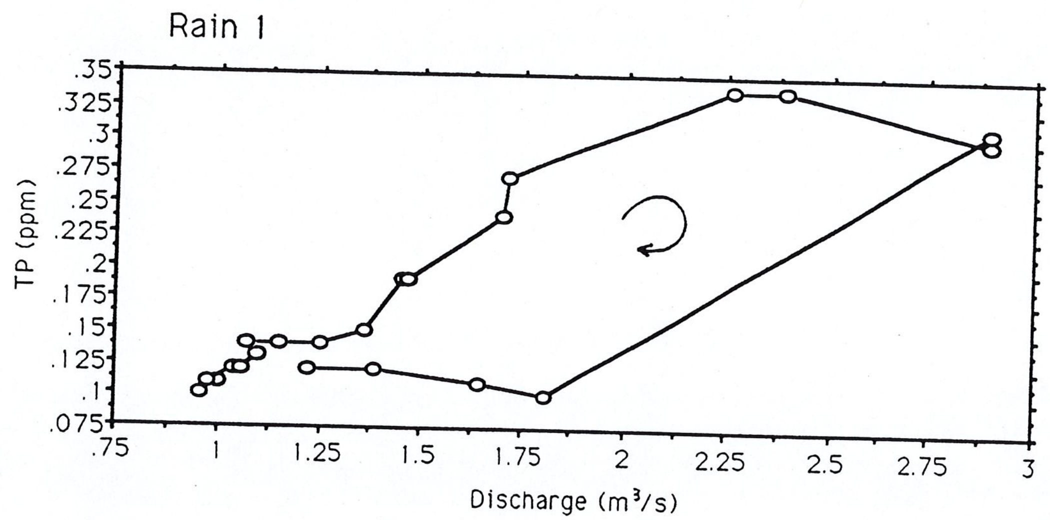
(c)



(d)

Figure 4 (c), (d)





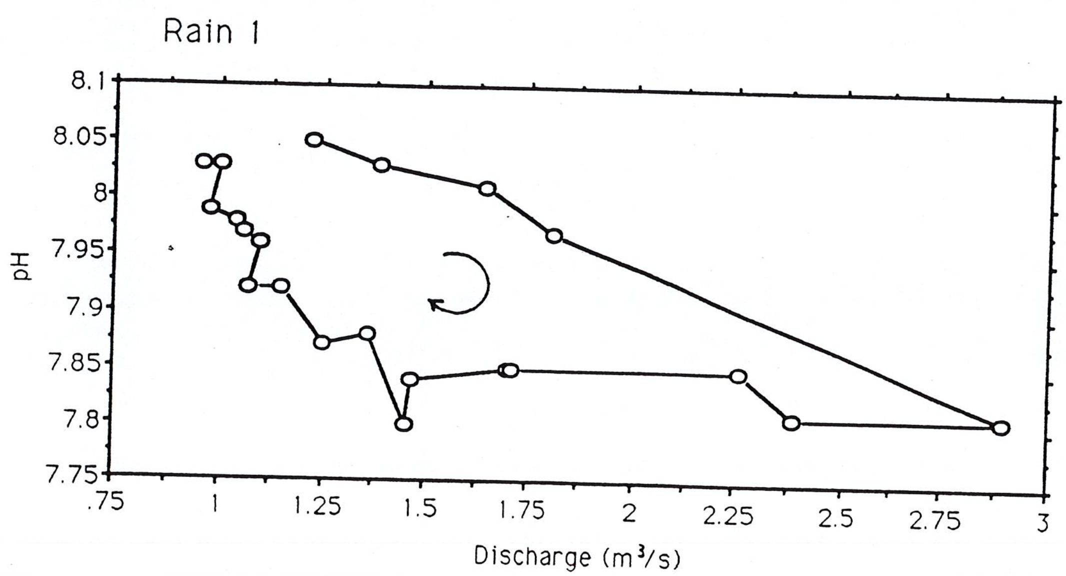


Figure 5 (a), (b), (c). Concentration versus Discharge

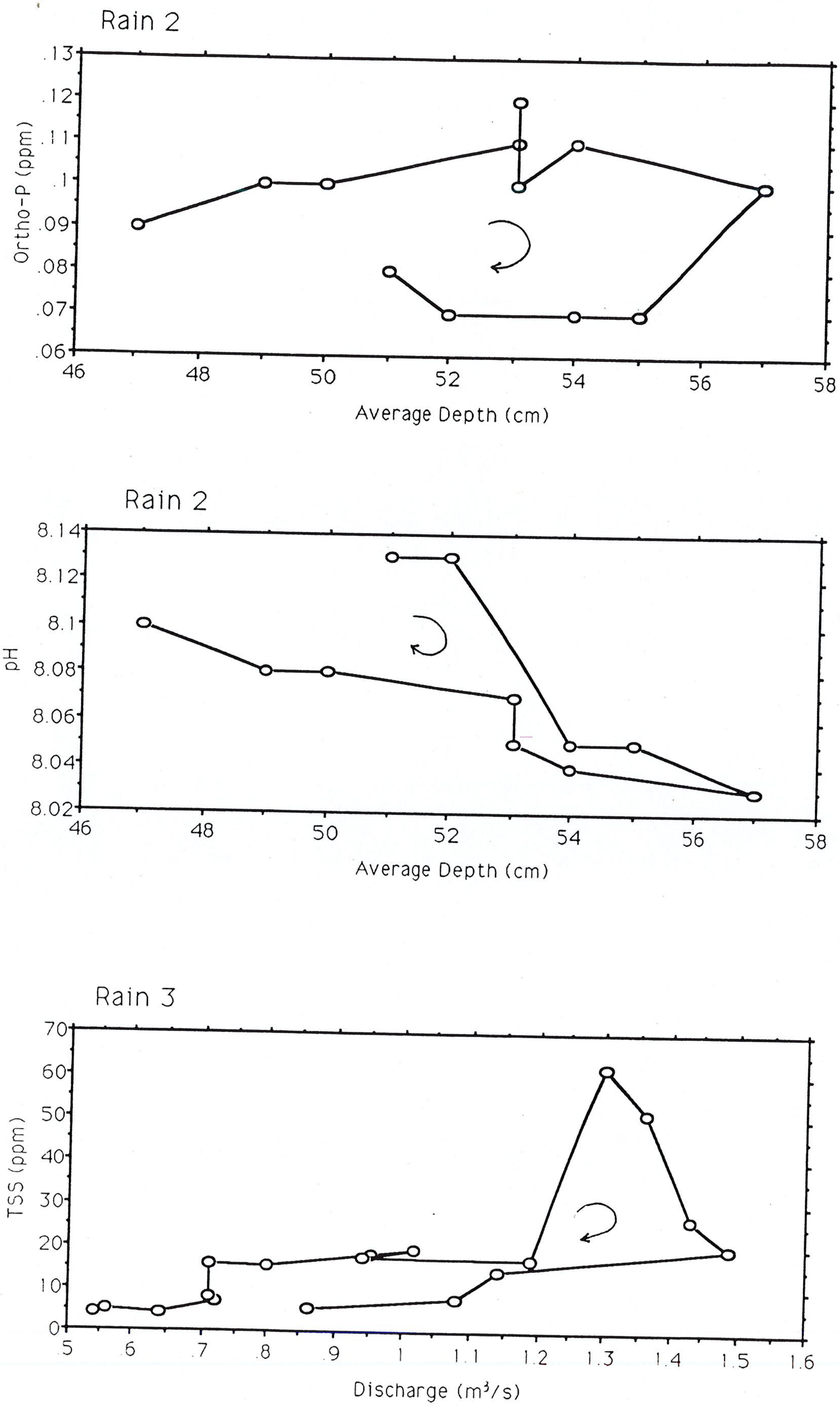


Figure 5 (d), (e), (f). Concentration versus Discharge

The common characteristics of changes in concentration during storm events have been discussed above. Some different results from different rains are summarized as follows:

(6) The concentration of K^+ and NO_3^- for Rain 1 decreases gradually with the increase of flow rate. However, there is an initial increase in K^+ and NO_3^- concentration for Rain 2, 3, 4, and 7. It is noticed that Rain 2, 3, 4, and 7 are thunder storms, and Rain 1 is a long duration rainfall. Also it is noticed that the higher the intensity of rainfall is, the higher the initial increase is. This phenomenon suggests that the type of rainfall affects the curve of K^+ and NO_3^- concentration . Further research about the initial increase in K^+ and NO_3^- is needed.

(7) For Rain 1, 2, 4, and 7, Cl^- concentration decreases with the increase of discharge. But during Rain 3, after a sharp initial peak, Cl^- is independent of discharge.

(8) The concentration of $SO_4^=$ is affected by rainfall but no certain trend exists except Rain 1 which shows a gradual decrease with the increase of discharge.

(9) Rains 1, 2, 3 show a continually increase in SiO_2 concentration during and after rainfall. That is, 24 hours after the end of rainfall the SiO2 concentration is still much higher than the concentration at beginning of the rain. But for Rain 4 and Rain 7, SiO2 concentration shows a peak during the rain, and recovered to initial level 24 hours

after the end of the rain. Therefore any type of rainstorm will cause an increase of SiO_2 transport.

(10) All the storms except Rain 1 show that DO concentration decreases as flow rate goes up. The reason is unclear.

(11) The concentration of Fe and Mn are less than 0.1 ppm (sometimes as low as blank). Thus we were unable to determine the dynamics of Fe and Mn during storms.

(12) A regression analysis indicate good relations between TSS and TP, and between Ca^{++} and Mg^{++}:

	Simple Regression (R- Squared)				
	Rain 1	Rain 2	Rain 3	Rain 4	Rain 7
TSS and TP	0.878	0.845	0.936	0.849	0.559
Ca^{++} and Mg^{++}	0.609	0.636	0.647	0.921	0.685

(confidence interval: 95%)

(B) Changes in Flux of Chemical Ions during Storm Events

During storms the flux (or export) of any chemical ion increases with the increase of discharge, although the concentration for some chemical ion decreases with the increase of flow rate (see Figure 6). This means the total amount of chemical ions getting into the EBWC during a rainstorm positively related to discharge.

(C) Effects of Intensity of Rain on Elemental Dynamics

The types of rainstorm -- high intensity but short duration (such as thunder storms), or low intensity but long duration, or low intensity and short duration -- have effects on the shape of concentration curves. Generally the concentration curve shows a much sharper peak or valley for a thunder storm than for a low intensity but long duration rainstorm (such as Rain 1). It is clear that the maximum intensity of a rain plays an important role for stream elemental dynamics. Good examples of this phenomenon are Rain 4 which has a relatively high maximum intensity of rain (15.2 mm/hr), and Rain 5 that has a relatively low intensity rain (2.16 mm/hr). Both of them are thunder storms. The length of time since the last storm is more than seven days for both Rain 4 and Rain 5. Figure 7 (a) represents the discharge of Rain 4. It shows two distinct discharge peaks which were caused by only one three-hour storm (15.2 mm/hr for the first hour, 11.42 mm/hr for the second hour, and 1.52 mm/hr for third hour). How could such a rain form two peaks of discharge? Figure 7 (b) shows that there are two peaks of concentration in hydrogen ion, and the first one corresponds to the first peak of discharge. Therefore, one might expect that the first peak of discharge is a result of the intensity of rain being greater than the infiltration rate so that a "flash" flow (surface and subsurface flow) is produced. The

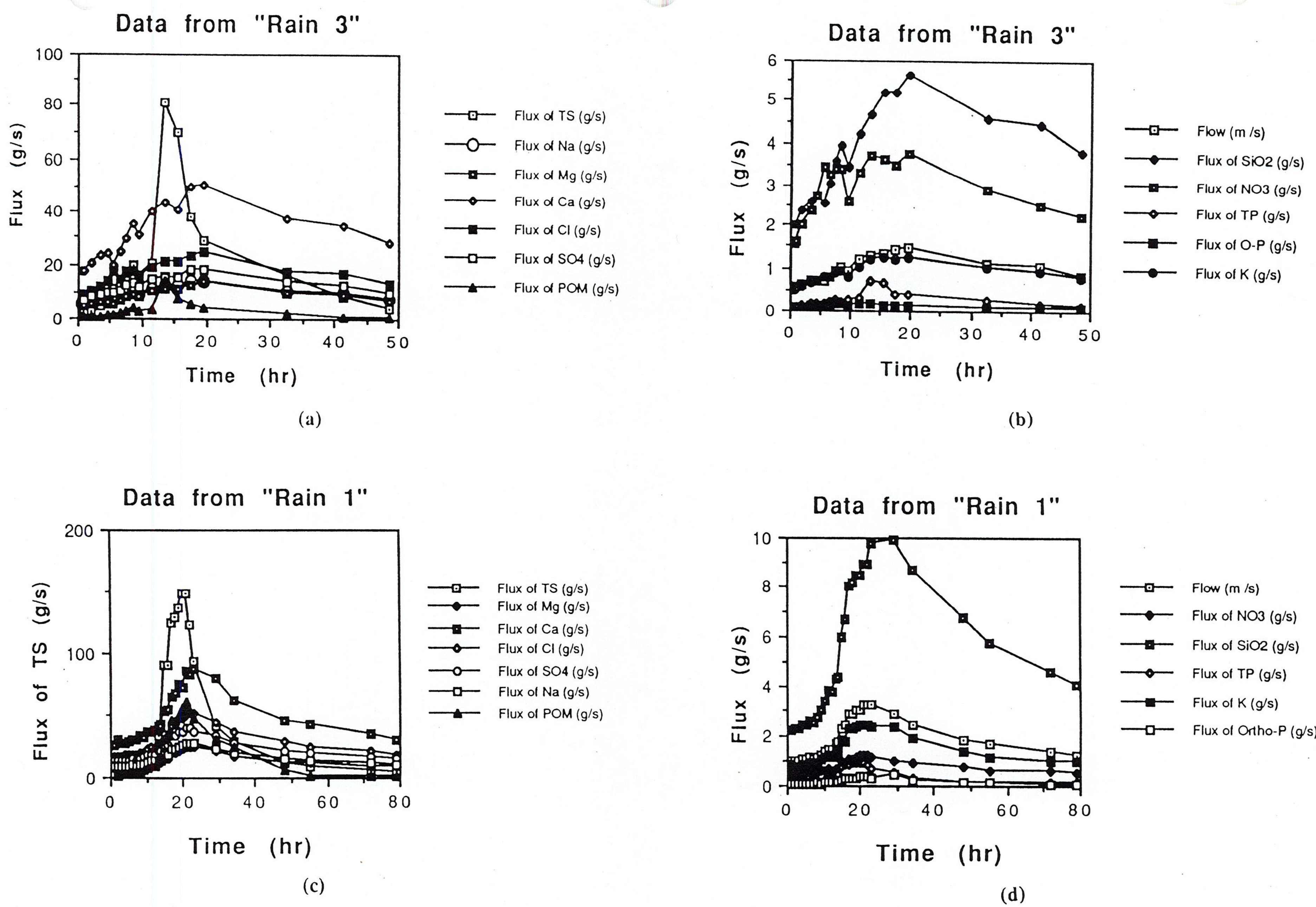


Figure 6. Flow rate and flux of chemical material for Rain 1 and Rain 3

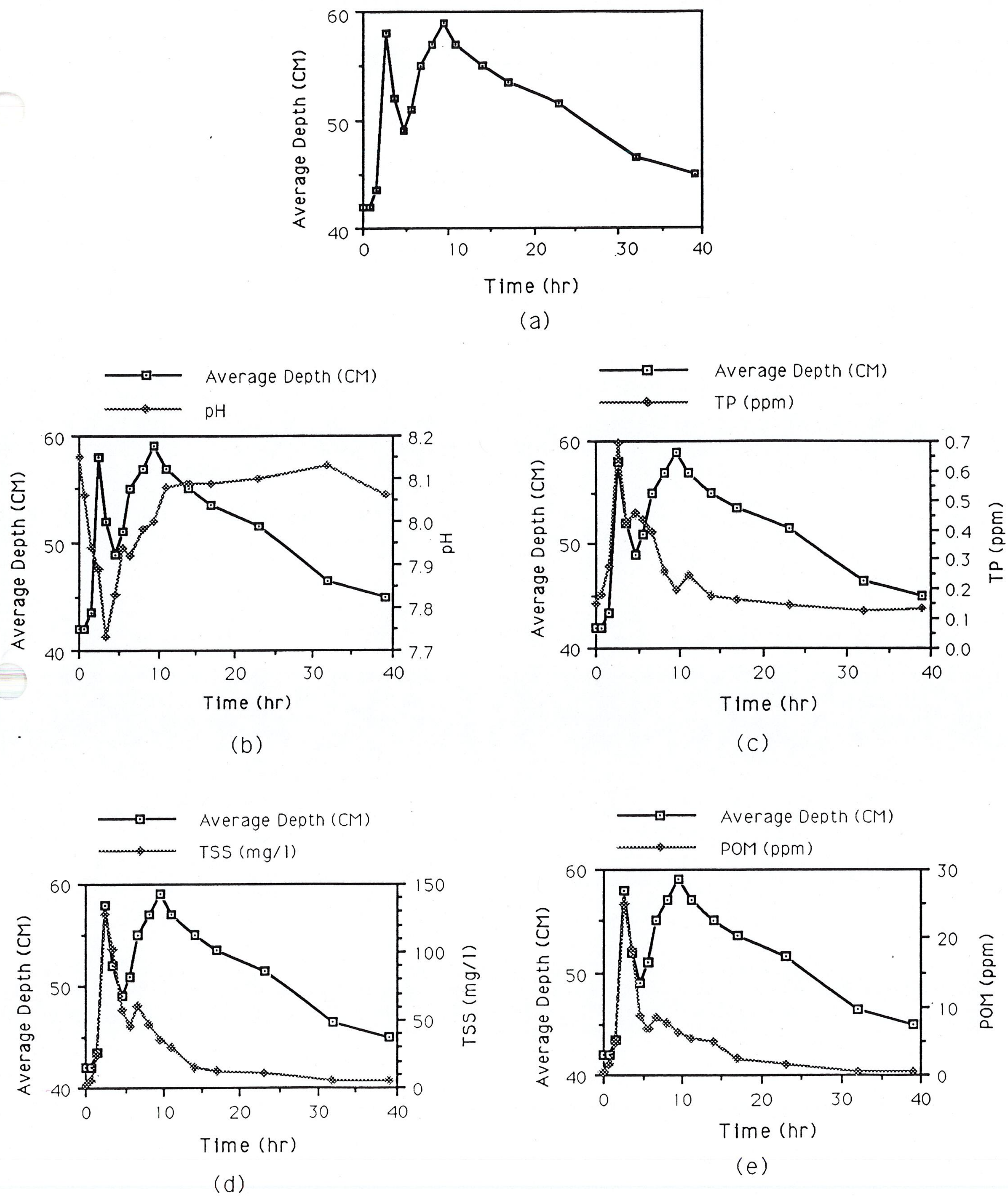


Figure 7. Changes in average depth, TSS, TP, Ortho-P and pH during Rain 4

second peak of discharge is a regular peak contributed by both stormflow and baseflow.

TP, TSS and POM (ppm) also has two peaks (Figure 7(c), (d), and (e)). The first peak is much higher than the second one, which supports the rapid washout phenomenon.

In contrast to Rain 4, Rain 5 has a very small maximum intensity of rain that causes small change in flow rate and concentration of chemical ions. The small response of the stream is probably because the intensity of rain is not great enough to produce stormflow.

Analysis here suggests that the elemental dynamics in a stream during storm events depend upon dynamics of baseflow and stormflow which will in turn be affected by the types of rainstorm (intensity and duration). However the question of what intensity of rain can cause a "flash" flow, and what intensity or duration of rain will not cause obvious changes in concentration and flux of chemical ion still need to be studied. Furthermore, some other factors, such as soil moisture, vegetation, the length of time between storm events, slope of watershed etc. must be considered to answer these questions.

(D) Effects of the length of time between storm events

Results from Bilby and Likens' study suggests "the magnitude of the concentration of fine particulate organic matter during a summer storm is very dependent on the length of time since the last high discharge. The fine particulate organic matter increases on the streambed during the dry period and then is washed downstream during the next high flow" (Bilby and Likens, 1979). The same result is obtained in this study. The data from Rain 3 include, actually, three "sub-rains". The time between Subrain 1 and Subrain 2 is 9 hours and 16 hours between Subrain 2 and Subrian 3. Although the intensity of rain for Subrain 1 and Subrain 3 are similar, the concentration in POM and Ortho-P for Subrain 1 are 1.6 and 1.8 times as high as for Subrain 3 respectively.

The concentration of K^+ and NO_3^- shows a much higher initial peak for Subrain 1 than those for Subrain 2 and Subrain 3. Some research has been done to determine the accuracy effect of the length of time between storm events on elemental dynamics. For example, Moore (1984) has developed a dynamic model to describe basin sediment yield including sediment availability function, removal function, and transition function. Further study is needed if we want to figure out the accurate and quantitative effect of the length of time between storm events on elemental dynamics in EBWC.

Conclusion

This is an pilot study on elemental dynamics of the East Branch of the Wappinger Creek during summer storm events. The trend of increasing concentrations of hydrogen ion, TSS, TP, POM, and Ortho-P with increasing discharge is clear. Precipitation is characterized as a dilute solution of Mg^{++}, Ca^{++}, Na^{+}, and Cl^{-} during rainstorms. After an initial increase, concentration in K and NO_3^- decreases with an increase in discharge. Concentration of SiO_2 increases during any storm event.

The stormflow and baseflow are main sources carrying chemical ions into a river during storm events. Intensity, duration of rain, the length of time between storm events impact the elemental dynamics in a river by acting on stormflow and baseflow. From this study it is clear that elemental dynamics in a river during a rainstorm will aid in the understanding of the hydrology of a river being investigated.

At the beginning it is argued that short term events such as storms have impacts on disturbance in streams. Aspects for further research may include: Impact of extreme heavy rainfall on elemental dynamics; impact of storm events on element availability to the biological community; and quantitative research of the hydrology of a river by studying elemental dynamics during a rainstorm.

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