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EFFECTIVENESS OF THREE "BEST MANAGEMENT PRACTICES" FOR REDUCING NON-POINT SOURCE POLLUTION FROM PIEDMONT TOBACCO FIELDS

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Several project staff had key roles during the project. Ms. Kathleen Summitt managed the field data collection effort and kept the often ill-tempered field instruments and data loggers in good working order. She also managed the data set and performed data analyses. Mr. Gene Nocerino supervised construction of the additional field flumes, instrument shelters, and grassed level spreaders.

ABSTRACT

We evaluated effectiveness of three BMPs for tobacco production: no-till (NT) versus conventional tillage (CT), grassed field-side filter zones (GFZs), and forested filter zones (FFZs) for two years. Level spreaders were installed within both FFZs and GFZs zones to convert channelized runoff into sheet flow. The primary objective was to test three BMPs in series to determine the total reduction in suspended solids and nutrients as runoff exited the lower flumes of the FFZs. A secondary objective was to compare yield and quality of tobacco from NT versus CT. Another secondary objective was to compare the effectiveness of the same FFZ first with a mature stand of pines and hardwoods, and later with vegetation following clear cutting. The study was conducted on the Oxford Tobacco Research Station in Granville County, North Carolina.

Total suspended solids (TSS) leaving tobacco fields were reduced by 70% to 90% by use of NT compared to CT. Nutrient discharge from NT and CT fields was so low that no clear trends were seen. There was a tendency toward slightly more nutrient release from NT than from CT fields which is consistent with previous reports by other authors. GFZs functioned very well in retaining solids and nutrients in early summer, but seemed to overload during late summer, probably due to limited infiltration capacity. Forested filter zones with their higher infiltration capacity, were able to back up the GFZs when they overloaded and exported sediment and nutrients to the FFZs. In combination, GFZs and FFZs retained 80 to 95 percent of all sediment and nutrients entering the zones, proving to be an extremely effective combination.

Dense ground vegetation in the cut-over FFZ more than doubled its capacity to effectively detain sediments and nutrients, compared to the effectiveness of the same FFZ when it was covered by a stand of mature mixed pine-hardwood. Detention rates jumped from 32% with a mature forest to 72% with dense ground vegetation which followed the clear cut. As found in our previous studies, a small number of major events each year accounted for at least 80% of all sediments and nutrients exported from the fields. In this study, one event in December, 2000 delivered more sediment to the filter zones than all other events monitored over the two year period.

In both crop years, yield was lower and grade was slightly lower for tobacco from NT compared to that from CT. In the first year, yields from NT and CT were below the regional average. In the second year, yields from NT and CT were higher than the regional average.

Based on this research, we recommend the use of some form of conservation tillage for tobacco and other tilled crops, and the use of grassed and forested filter zones with level spreaders.

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SUMMARY AND CONCLUSIONS

We evaluated effectiveness of three BMPs for tobacco production: no-till (NT) versus conventional tillage (CT), grassed field-side filter zones (GFZs), and forested filter zones (FFZs) for two years. Level spreaders were installed within both FFZs and GFZs zones to convert channelized runoff into sheet flow. The primary objective was to test three BMPs in series to determine the total reduction in suspended solids and nutrients as runoff exited the lower flumes of the FFZs.. A secondary objective was to compare yield and quality of tobacco from NT versus CT. Another secondary objective was to compare the effectiveness of the same FFZ first with a mature stand of pines and hardwoods, and later with vegetation following clear cutting. The study was conducted on the Oxford Tobacco Research Station in Granville County, North Carolina.

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In both crop years, yield was lower and grade was slightly lower for tobacco from NT compared to that from CT. In the first year, yields from NT and CT were below the regional average. In the second year, yields from NT and CT were higher than the regional average.

Based on this research, we recommend the use of some form of conservation tillage for tobacco and other tilled crops, and the use of grassed and forested filter zones with level spreaders.

RECOMMENDATIONS

Tobacco and other tilled crops should be grown with an effective form of conservation tillage to effectively minimize delivery of sediment to receiving waters. Reductions of sediments of 70% can be made and would go a long way toward restoring sediment impacted waters. Indications were that yields from no-till are lower than from conventional tillage, thus cost-share payments may be appropriate to supplement the practice. On the other hand, retention of so much soil in farm fields, which under conventional tillage was routinely lost, should eventually help to increase yields and/or lower costs of crop production.

Grassed filter zones, adjacent to farmed fields, should be used for the first phase of reduction of sediments and nutrients in agricultural runoff. Grassed zones are typically low in infiltration capacity because of the tightness of the sod and compaction caused by equipment. We recommend use of level spreaders in grassed zones when they would effectively improve the utilization the available area. We recommend establishing woody-stemmed cover crops such as lespedeza in the lower portion of the grassed zones, next to the woodland filter zone. We do not recommend that grassed filter zones be relied upon as the only filter zone for a farm field because they are typically inadequate to handle the large events which are the events which deliver most of the sediments and nutrients to receiving waters.

We recommend the use of forested filter zones where they are adjacent to agricultural fields, and in some cases the planting of forested, brushy and grassed filter zones. If topography or hydrologic engineering concentrate runoff in the zone, level spreaders should be installed in the in the upper end of the zone. Vegetation in all zones should be managed to encourage growth of dense, woody ground vegetation, except in the upper portions of the grassed zone. If available forested zones are too small in area or otherwise only partially functional, removing the overstory would be expected to greatly improve performance of the filter zone. This practice may also address shading and/or root competition problems for farm field edges. Note that if any portion of a field-side filter zone is riparian, restrictions may apply to manipulation of vegetation and/or other activities within all or portions of the zone.

INTRODUCTION

Non-point source pollution (NPSP) from agricultural runoff is a major concern regarding water quality throughout the state of North Carolina, the southeastern region and the nation. Farmers are being encouraged to adopt best management practices (BMPs) to conserve soils and reduce NPSP. Many studies have evaluated individual BMPs such as conservation tillage, grassed filter zones (GFZs), or forested filter zones (FFZs) in reducing NPSP. However, on most agricultural watersheds, multiple BMPs can be used in series to provide maximum NPSP reduction and to maintain soil productivity. As an example, conservation tillage and vegetated filter zones are frequently recommended, but little research has been done documenting effectiveness of a complete system consisting of no-till, grassed and forested filter zones.

Widespread adoption of new BMPs may be accelerated with estimates of NPSP reductions and estimates of effects on crop yields and quality, especially for a high-value cash crop such as tobacco. Tobacco was considered to be a good crop to use for this study because heavy cultivation and heavy applications of fertilizers are conventionally used. If a system of BMPs can handle runoff from tobacco fields in the Piedmont, it can probably handle most other field crops. Tobacco is North Carolina's most important crop in terms of income to growers with about 240,000 acres of flue-cured tobacco and about 8,000 acres of burley (Worsham *et al.* 2000). Tobacco accounts for about 45 percent of the income from all crops in the state with an estimated gross income of just under $1 billion.

As a BMP, field-side FFZs are widely regarded as having high potential for reducing agricultural NPSP. Yet, there has been very little research to improve FFZ efficiency through management of woody vegetation. However, vegetation management practices should be able to improve FFZ efficiency by increasing physical impediments to storm flow, plant uptake of nutrients and microbial transformation of specific nutrient forms. For example, it has been suggested that FFZ effectiveness could be improved through timber harvesting by "renewing" plant uptake capacity (Lowrance *et al.* 1984), but this has not been documented.

Our previous research has shown that eighty percent of total potential pollutants that enter filter zones annually are delivered in the largest four to eight events per year (Franklin *et al.* 2000). We also demonstrated that NPSP from these large events is detained by FFZs and slowly released later in winter and early-spring events. Buffering large releases of NPSP may be a more important function of field-side FFZs than long-term reductions through plant uptake. We believe that vegetation management to increase woody ground vegetation will improve the ability of filter zones to detain pollutants by physically slowing storm flow so that sediment and nutrients are dropped in the zone even if infiltration does not take place. This is especially important during major events when infiltration capacity of most zones will be inadequate for large volumes of storm flow.

OBJECTIVES

Our overall objective was to compare the effectiveness and costs of three BMPs for tobacco production including no-till (NT) versus conventional tillage (CT), grassed and forested filter zones. Specific objectives were to:

(1) Compare NT to CT practices for tobacco in terms of infiltration of rainfall, yields of sediment and nutrients to field edges, crop yields, and leaf quality.
(2) Document the effectiveness of GFZs and FFZs in terms of infiltration of rainfall and removal of sediment and nutrients along field edges.
(3) Compare performance of the FFZ in Watershed I as after a clear cut of all forest vegetation to its performance with a mature mixed pine-hardwood forest.
(4) Document the total benefits and costs associated with use of this completely integrated system of three BMPs.

REVIEW OF LITERATURE

NON-POINT SOURCE POLLUTION IN THE SOUTHEAST

The substantial contribution by agriculture to nutrient and sediment loads of streams, rivers, and lakes has long been recognized (Smolen and Shanholtz 1980). In response, best-management practices have been developed and implemented for southeastern agricultural lands to reduce these inputs. Despite these efforts, however, a recent North Carolina Non-point Source (NPSP) Assessment (NCDNRCD 1989) observed that approximately 30% of all streams and rivers in North Carolina have been assessed as not supporting or only partly supporting their designated use due to NPSP pollution. In these degraded waters, 67% of NPSP pollution was due to agriculture. This observation is consistent with the recent observation that between 40 to 70% of soil test results reported by a majority of states in the southeastern United States are rated as high or excessive in P content (Sims 1993). Agriculture was similarly considered to be responsible for degradation of some lakes and estuaries. Ten southeastern states recently reported that agricultural NPSP pollution affected greater than 50% of their waters (Neary *et al.* 1989). These data demonstrate that agriculture contributes a substantial proportion of NPSP pollution to surface water throughout the southeast.

CONSERVATION TILLAGE

Conservation tillage results when some or all of the residue from the previous crop is left on the soil surface to effectively reduce soil erosion. Use of conservation tillage has other environmental implications as well. Generally, the term "conservation tillage" includes those practices where more than 30 percent of the soil surface is covered with crop residue (Unger 1990). Water as surface runoff and subsurface drainage serves as a carrier for dissolved chemicals. Soil suspended in surface water also serves as a carrier of sediment-adsorbed chemicals. Use of conservation tillage affects chemical losses by trapping soil and by increasing infiltration and chemical exchange of dissolved chemicals (Baker and Laflen 1983).

Conservation Tillage and Runoff

In many studies, crop residue on the soil surface has been shown to reduce surface runoff from all but the heaviest storms (Baker and Laflen 1983; Barisas *et al.* 1978; Hamlet *et al.* 1984; Johnson *et al.* 1979; Laflen and Tabatabai 1984; Mostaghimi *et al.* 1991; Schreiber and Cullum 1992,1998) and eliminate runoff from most small storms (Baker and Laflen 1983). On Manor loam soils in Maryland, surface runoff was over nine times greater from conventional-tillage corn compared with NT corn. However, on a poorly drained clay loam in southern Ontario, conservation tillage for corn increased surface and reduced subsurface tile drainage relative to CT (Gaynor and Findlay 1995). The authors attributed these results to increased spring soil moisture for conservation tillage on these soils. Several other researchers have found that NT may sometimes produce more runoff than CT (Lindstorm and Onstad 1984; Mueller *et al.* 1984).

Conservation Tillage and Sediment

Conservation tillage has been used to reduce soil erosion and most studies have documented its effectiveness. The degree of reduction of soil loss depends on soil parameters, rainfall intensity, amount of crop residue, and whether the conservation-tillage practice included some tillage at crop establishment such as strip tillage. Smith *et al.* (1995) found that soil loss in NT soybeans was reduced by one hundred fold compared with CT on silt loam soils in northern Mississippi. McDowell and McGregor (1980) found a similar relative range of reductions when NT soybeans and corn were grown on highly erodible loessial soils in north Mississippi. The average annual losses for the two-year period from NT soybeans, planted directly through previous crop residues, was only 0.3 metric tons per hectare (NT/ha) compared to 29 NT/ha from CT. Johnson *et al.* (1979) compared two conservation tillage systems with CT for continuous corn on deep loess soils in Iowa. During three growing seasons, conservation tillage systems on the average reduced soil loss 60 to 90 percent.

Conservation Tillage and Nutrients

Whereas most studies have documented reduced soil loss with conservation tillage, results are variable with respect to nutrients. Barias *et al.* (1978) and Johnson *et al.* (1979) found that soluble-nutrient losses increased with conservation tillage due to crop residues as a source of nutrients, and to lack of fertilizer incorporation. Other investigators also indicated that the concentrations of soluble nutrients may be high in surface runoff from conservation tillage, even though soil loss is low (McDowell and Gregor, 1980; Laflen and Tabatabai, 1984; and Schreiber and Cullum, 1992). Mostaghimi et al. (1991) studied the effects of NT and CT systems and fertilizer application methods on nitrogen losses from croplands. They found that N losses were highest when fertilizer was surface applied in CT, and lowest when fertilizer was incorporated in the NT system. With conservation tillage and reduced or no incorporation of nutrients, less mobile nutrients such as P and K can be stratified within the soil profile (Baker and Laflen 1983). Andraski *et al.* (1985) in their review of tillage studies point out that total P losses have generally been found to decrease due to soil loss reductions with conservation tillage systems. Logan *et al.* (1987) found higher rates of infiltration with conservation tillage which in some cases led to higher levels of subsurface nitrogen.

Conservation Tillage and Tobacco

Peedin and Smith (2001) have expressed the view that "growing flue-cured tobacco by the no-till method is the best option ... to meet conservation compliance requirements" thus avoiding loss of government support programs for the whole farm. They review results from comparison tests of conservation versus CT tobacco in the Piedmont and Coastal Plain from 1993 to 1999. In all cases, tobacco was successfully grown with conservation tillage, but in most cases yields were lower than for CT.

FORESTED FILTER ZONES

Forested filter zones provide an especially good opportunity to reduce NPSP from agricultural runoff. Farmers own roughly one third of the nonindustrial private forest lands in the southeast, much of it bordering fields. These borders are usually forested because they are too steep or wet for agriculture, but many can serve well as FFZs. Within the past 15 to 20 years agronomists have begun to recognize the importance of FFZs as valuable filters for agricultural runoff. However, there has not been agreement in the scientific literature concerning the effectiveness of FFZs.

Researchers using various approaches have concluded that forested filter zones may reduce nutrients and sediments reaching receiving waters from agricultural runoff. Hill (1981) measured P output from 22 watersheds but did not directly measure field runoff. He found positive correlations between P and crop area, and negative correlations with forested area. In a case study of the Chowan River watershed in North Carolina, Craig and Kuenzler (1983) estimated that swamp forests removed 83% of the total nitrogen (N) and 51% of the total P passing through them.

Other researchers, particularly those in the North Carolina Coastal Plain, have demonstrated the effectiveness of FFZs by examining the drainage patterns and directly measuring volumes of runoff through the filter zone. Jacobs and Gilliam (1983) found that a 16-meter-wide zone was effective in one study in removing nitrate. In another North Carolina study, Cooper (1985) measured Cesium-137 from soil profiles along transects across two Coastal Plain streams to study sediment redistribution within the last 20 to 25 years. He found that 15 to 50 cm of sediment was deposited at the forest edge while less than 5 cm was deposited in the flood plain. About 80% was deposited within the first 100 m of the FFZ. This was particularly significant, since many nutrients and chemicals are bound to soil particles. Cooper also measured P in the transects and found that 50% of the P remained in the sediments within riparian areas while 50% left the watershed in drainage waters. Other researchers have also demonstrated that forested filter zones significantly reduced sediments and nutrients IN agricultural runoff: (Franklin *et al.* 1992, Franklin *et. al* 2000, Verchot *et al.* 1996, 1997a, 1997b, 1998; Peterjohn and Correll 1984, Lowrance *et al.* 1984a, Lowrance *et al.* 1984b, Jacobs and Gilliam 1983, Parsons *et al.* 1990, Phillips 1989, and Doyle *et al.* 1975).

FORESTED VERSUS GRASSED FILTER ZONES

Whereas, forested filter zones have been shown to be effective in reducing NPSP from agricultural sources, results regarding GFZs are mixed (Madgette *et al.*, 1989, Daniels and Gilliam, 1989; Dillaha *et al.* 1989) with results suggesting that GFZs may be effective for particulate and sediment-bound nitrogen (N) including organic and adsorbed NH_4-N and relatively ineffective for dissolved N (NH_4-N and NO_3-N). In addition, grass can be quickly submereged by runoff rendering these zones ineffective (Hayes *et al.* 1983). Others have felt that GFZs may offer specific characteristics which may compliment other types of vegetation when used together in filter zones with mixed vegetation.

Schultz *et al.* (1995) noted deficiencies in GFZs compared with FFZs and proposed a vegetated filter zone (VFZ) consisting of trees, shrubs, and grasses to take advantage of the differing above- and below-ground structures of different plant forms. Welsch (1991) proposed a three-zone VFZ system where channelized runoff would be distributed within a field-edge GFZ approximately 6 m in length (up-slope to down-slope). Nutrient "trapping" would primarily be accomplished by a two-zoned FFZ. The up-slope FFZ would be approximately 18 m in width and would have periodic timber harvesting to remove sequestered nutrients. The second and stream-side FFZ would be about 5 m in width and would not be harvested.

Verchot *et al.* (1997b) noted that when GFZs and FFZs are adjacent, attenuation of NO_3-N in sub-surface flow due to denitrification occurs under the forested rather than grassed portions of the zone due to higher concentrations of dissolved organic carbon deeper in the soil profile in the FFZ.

BENEFITS OF DISPERSING RUNOFF

Even though best-management practices are extensively used throughout the southeast, NPSP pollution from agricultural runoff continues to be a serious water quality problem. This is the case within certain large watersheds, although forested filter zones would seem to be adequate (Phillips 1989). Several recent studies have indicated that filter zones sometimes do not function as some literature would suggest because of channelized flow through the riparian areas (Nutter and Gaskin 1989). In a simulated feedlot study, Dillaha *et al.* (1986a) observed that GFZs with channelized flow were much less effective than those with shallow uniform flow. Dillaha *et al.* (1986b) visited 33 Virginia farms and found that most sites had topographic limitations which limited filter zone performance by concentrating field runoff in natural drainageways before it reached the filter zone. Dillaha *et al.* (1989) have recently concluded that operational vegetated filter zones were not as likely to be as effective as experimental ones because of channelized flow.

We conducted a preliminary study designed to test the feasibility of water quality improvement through dispersed runoff (Franklin *et al.* 1992) and we have also completed a study of nitrogen cycling within grassed field edges and FFZs (Verchot *et al.* 1996, 1997a, 1997b, 1998). We have recently completed an additional four-year study which has expanded the monitoring and analysis of surface hydrology (Franklin *et al.* 2000). During the four years of observations, absolute discharge, discharge relative to contributing watershed area, and discharge as a percent of precipitation were less at the lower flume when compared to the upper flume in both watersheds (Franklin *et al* 2000). Thus, less water volume reached receiving waters as surface runoff. Flow detention during natural events resulted in significant reductions in ammoniacal N (NH_4N), nitrate N (NO_3N), total N (TN), orthophosphate (OP), total P (TP), and total suspended solids (TSS). We found that on the average 46% of total suspended solids on an area basis were deposited in a riparian-type filter zone when flow was dispersed compared with 28% for channelized events. On a second somewhat larger hillside FFZ, 73% of total suspended solids on an area basis were deposited in a riparian-type filter zone when flow was dispersed compared with 46% for channelized events. However, no estimate was made on the effectiveness to "trap" specific soils fractions, especially clay and fine silts. Without effective utilization of the FFZ by flow dispersion, FFZs more efficiently trap courser sands and silts while fine materials of high specific surface area reach streams (Correll 1994) or are at least carried deeper into the FFZ (Cooper and Gilliam 1986) where they can be more easily transported later to surface water or where nutrients and pesticides can be desorbed and later transported.

We created artificial events using irrigation pumps simulating a one-year return period event. Half the events were nondispersed and half were dispersed. Dispersion reduced peak discharge at the lower flumes and increased infiltration. Results were statistically significant.

An additional two-year study of filter zones and level spreaders was funded by the North Carolina Division of water Quality (Hazel 2000) The main objective of this research was to evaluate different level spreader designs and configurations for dispersing channelized agricultural runoff and to evaluate them for enhancing VFZ effectiveness on several sites with greatly differing watershed characteristics. Other objectives included estimating construction and maintenance costs and developing recommendations for level spreaders for specific watershed and VFZ conditions.

Level spreaders with associated instrumentation were constructed on six watersheds representing a wide variety of watershed and VFZ conditions. Spreaders without associated instrumentation were constructed on three watersheds. Source areas included crops under both conventional and conservation tillage, a pasture, a dry-lot for dairy cattle, and a paved and partly-roofed cattle containment area. All spreaders tested were designed to be permanent installations. Designs tested included commercial galvanized gutters, treated wood, fabric-lined ditches with gravel just above and below the ditch, and vegetated berm and trench.

Reductions in NPSP through-puts were a function of filter zone size, input concentration, runoff volume, and season. All spreader designs improved VFZ performance. Level spreaders with larger cross-sectional areas were more effective for high peak-flow events. However, spreaders with limited cross-sectional such as above-ground gutters have potential where excavation of ditches or shaping of spreaders with large equipment is a problem such as in forests or on steep slopes. The most easily maintained design is a vegetated berm and trench spreader shaped from soil. However, its use is practical only where tree roots are minimum and where farm equipment can maneuver during installation. This design also allows limited vehicle traffic over the spreaders.

METHODS

EXPERIMENTAL WATERSHEDS

Two 1.6 ha watersheds were instrumented for previous UNCWRRI-funded studies (Franklin *et al.*, 1992, Franklin *et al.* 2000). The watersheds included fields and forested areas, and are typical of farm watersheds in the Piedmont throughout the southeast.

Each watershed contained four fields from which surface runoff drained into a grassed waterway, through a field-side flume, into a GFZ. Runoff left the GFZ of each watershed as channelized flow which was then dispersed with level spreaders as it flowed into the FFZ. A flume at the lower end of the FFZ provided samples and measurements as runoff left the FFZ. The effective portion of the FFZs made up 7.5 and 14.3 percent of watersheds I and 11 respectively (Table 1). Soils in Watershed I were Helena loamy sand (Aquic Hapludult), Vance sandy loam Typic Hapludult) and Durham sandy loam (Typic Hapludult). Soils on Watershed II were Vance and Durham sandy loams.

Tobacco Tillage Comparison

The field portion of each watershed consisted of two fields where opposite sides of each field drained into a grassed waterway (Figure 1). In each watershed, one field was designated for CT, the other for NT tobacco. The four fields were roughly comparable in size, soils, and slope (Table 1). For each study year on all fields, a rye cover crop was grown during late fall through mid-spring. Then CT tobacco was grown in one field and NT tobacco in the adjacent field of each watershed (Figure 1).

The cover crops were established during the falls of 1998, 1999, and 2000 for all four fields by disking, fumigating, shaping tobacco beds, and then sowing abruzi rye (Table 2). In spring, each field on which CT was assigned was disked in late April and re-bedded just before transplanting. In fields where NT tobacco was to be grown, the rye cover crop was sprayed with herbicide twice in late April or early May prior to transplanting (Table 2).

Tobacco was planted for both tillage treatments the same day each year. In 1999, nursery-grown bare-root transplants were used for both treatments. In 2000, greenhouse-grown containerized transplants were used for both treatments. The tobacco variety used each year was K-346. Planting for both tillage treatments in 1999 was accomplished by using a conservation tillage transplanter developed collaboratively by researchers at VPI & SU and a Virginia farmer. The transplanter was designed to disturb only a narrow width of the bed to minimize the amount of weed seed that are brought to the surface. In 2000, both the conservation tillage transplanter and a conventional tobacco transplanter were used. Each row was identified with a stake indicating watershed, treatment and row number.

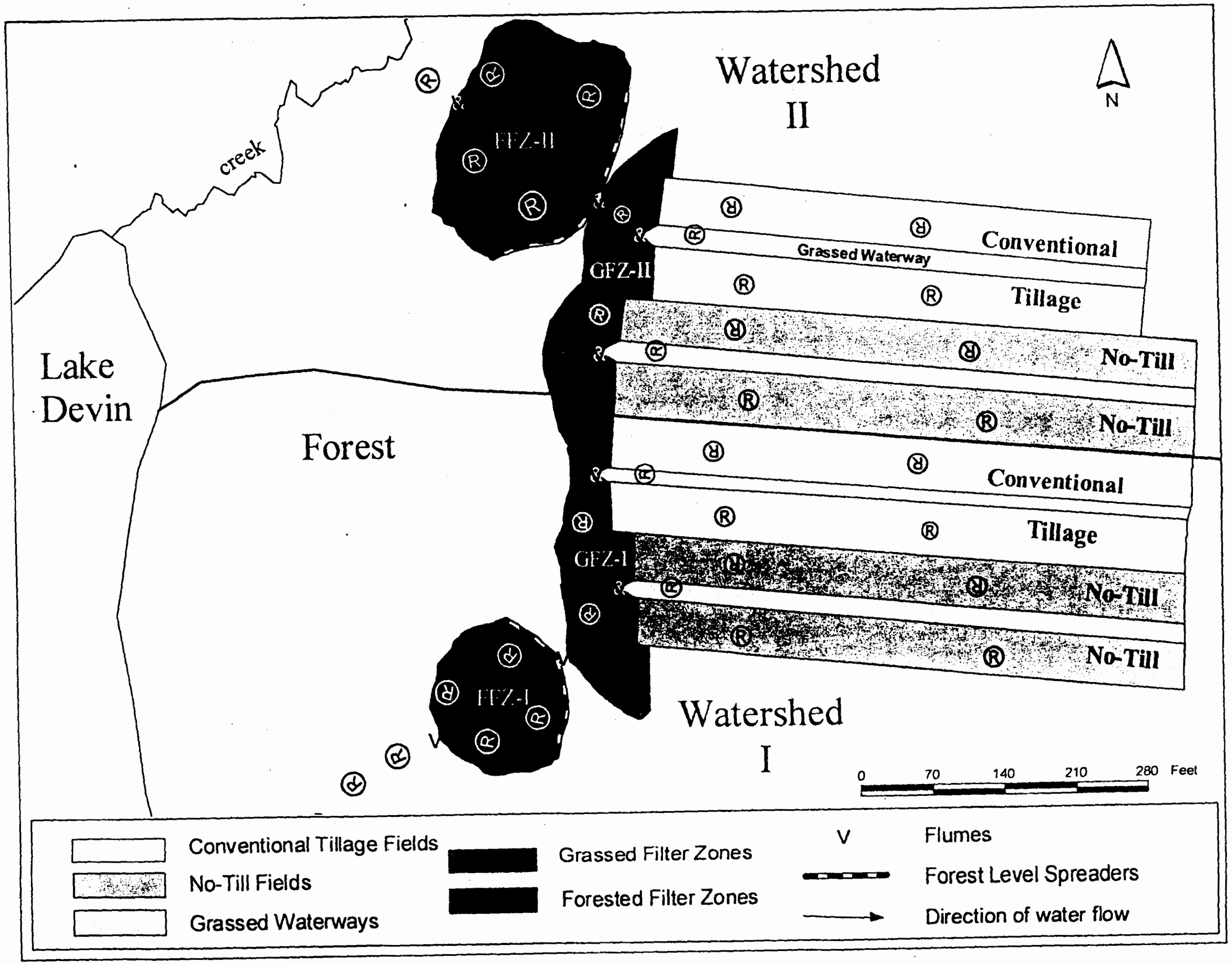

Figure 1. Site map of experimental watersheds at the Oxford Tobacco Research Station showing tillage fields, grassed filter zones (GFZ) and forested filter zones (FFZ).

Table 1. Descriptions of experimental Watersheds I and II

	Watershed I	Watershed II
Total area of watershed	1.29 ha	1.38 ha
Conventional tillage tobacco field area	0.47 ha	0.41 ha
Conservation tillage tobacco field area	0.43 ha	0.47 ha
Area in improved waterways	0.12 ha	0.11 ha
Grassed field edge filter zone area	0.14 ha	0.12 ha
Total forested filter zone area	0.13 ha	0.26 ha
Effective forested filter zone area with flow dispersed using level spreaders	0.12 ha	0.21 ha
Effective forested filter zone area as a percent of total watershed area	7.5 %	14.3 %
Average slope of field	5 %	6 %
Average slope of filter zone	5 %	7 %
Length of filter zone (distance between upper and lower flume)	42.83 m	47.84 m
Width of filter zone (across slope)	44.00 m	65.00 m
Total length of two level spreaders in grassed filter zone	28.82 m	23.42 m
Total length of two level spreaders in forested filter zone	49.24 m	66.50 m

Cultivation practices followed recommendations of (Collins and Hawk 1963, NCCES 2001, Peedin and Smith 2001) with regard to uses of pesticides, fertilizers, rates and timing of applications. The only exception was that herbicides labeled for conservation tillage tobacco were used on both treatments (Appendix Table 1). Irrigation was used when needed.

To compare tobacco yields and quality between tillage treatments, tobacco was bundled by half rows and tagged with the same label as the stake described above. Tobacco was cured, weighed and graded by bundle. A price index[1] based on regional averages for each year was used to determine value of the crop rather than actual receipts (Appendix Table 1).

Grassed Filter Zones

Grassed filter zones with a mixture of fescue and coastal Bermuda grass were located down-slope from the fields. However, storm-flow from each of the four flumes remained mostly channelized in a roughly 2 to 3-meter width through the zone. To try to enhance GFZ performance, a low, grassed level spreader was built below each field flume in fall, 1999. Level spreaders were well grassed before initiation of sampling during the 2000 crop season (Figure 1). Spreaders were constructed to permit trafficking over them by trucks, tractors, and other farm vehicles. Costs for installation and maintenance during 2000 were recorded.

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[1]1999 and 2000 Flue-Cured Tobacco Grade Prices. Prepared by the Official Variety Testing Program, Crop Science Department, North Carolina State University, Raleigh, NC 27695

Forested Filter Zones

Runoff from each GFZ entered the flume at the upper edge of the FFZ where it was sampled and measured. During this study, runoff for all events was dispersed on contour across the forested area using level spreaders. Level spreaders consisted of two treated wooden troughs extending laterally from each side of a distribution box. The wooden spreaders were placed along the contour to allow water to flow over the whole FFZ.

During our previous studies on these watersheds, both FFZs were fully stocked with mature trees (Franklin *et al.* 1992, Franklin *et al.* 2000, Verchot *et al.* 1996, 1997a, 1997b, 1998). In September 1996, most trees within the Watershed I FFZ were uprooted by Hurricane Fran. In the spring of 1997, a few remaining, standing trees and all downed trees within the FFZ were removed with a large crane positioned outside the FFZ. The crane was also used to right overturned stumps. Thus, during this study, the FFZ on Watershed I was considered to be functioning as a recently clear cut FFZ. The overstory on the Watershed II FFZ was essentially untouched by the same storm and remained a fully stocked, mature forest stand of mixed pine-hardwoods during this study.

INSTRUMENTATION

Flumes, Samplers and Data Recorders

Four 47-cm H-flumes were installed in 1998 in the lower end of each of the four grassed waterways which drain the four tobacco fields (Figure 1). Two 61 cm H-flumes between the GFZs and FFZs, and two 61-cm H-flumes at the lower end of each FFZ were re-activated for this study. Plywood wing-walls extended out from each of the eight flumes to direct runoff into the flumes. Wingwalls extended approximately 30 cm below ground and were set into a concrete base. Each of the eight flumes contained an integral stilling well that facilitated measurement of stage using float-driven potentiometers monitored by a Campbell CR-10 data logger. One data logger monitored all four field flumes. The upper and lower FFZ flumes were monitored by a data logger for each watershed. Each of the three loggers monitored one of three tipping-bucket rain gages. One logger was equipped with a 12-volt modem for monitoring general conditions. The site was equipped with both electric and telephone service.

Potentiometers were queried every two and one-half minutes for flume stage. If an absolute change in stage of 0.5 mm or more occurred since the last query, stage was recorded and change in stage was added to a designated logger register. Otherwise, stage was recorded every 15 minutes. When a total of 50 mm absolute change in stage occurred within a two-hour period, a 24-bottle automatic sampler was activated to take a sample and the change-of-stage register was zeroed. Both ISCO and American Sigma samplers were used. Rainfall measured by the tipping-bucket rain gauges was stored as five-minute totals.

REVISED RATING TABLES FOR FIELD FLUMES

Flumes are fabricated open-channel flow-measuring devices that consist of three sections that converge, restrict, and expand flow in a deliberate fashion (Gwinn and Parsons 1976). The H-flume was designed by the Soil Conservation Service for estimation of low volume flows from experimental watersheds. If published, empirically-derived rating tables or models are to be used, rigid design and installation specifications and methods must be followed (Brakensiek *et al.*1979). Any deviation from the design requires field calibration that is not generally performed due to the normally impractical requirement that large volumes of water be delivered in a well-monitored manner.

Calibration of GFZ and FFZ Flumes

During previous studies on the Oxford site (Franklin *et al.* 1992), it was observed that mid- to high flow rates appeared turbulent, possibly due to shorter-than-specified approach sections. All other specifications were measured and found to be within published tolerances (Brakensiek *et al.* 1979). This led us to question the wisdom of using standard discharge equations for determining flow rates and ultimately sediment and nutrient flow through the watersheds. The permanency of the site required calibration rather than alteration of the approach section to conform to specifications. Prior to calibration, wooden baffles were built outside the approach section of all flumes to lower velocities and provide more uniform flow throughout the cross-section of the approach sections.

For field calibration, two irrigation pumps were used to supply water at constant flow rates via two 12.7 cm irrigation pipes. Flow rates were controlled using the pump engine throttles and valves at the pipe outflow just above the flume. Flume stage was measured using a data logger and potentiometers to monitor stilling-well floats. Medium and high flow (0.24 to 6.86 m^3 /min.) calibrations were determined by measuring stage height for a constant flow rate using two paddle-wheel flow sensors installed in the irrigation pipes. Because flow sensors were erratic below a flow velocity of .30 m/sec, low flow rates (0.0060 to 0.240 m^3 /min.) calibrations were done by timing the filling of a 21.30 liter bucket at constant flume stage. Regression equations were developed from the data acquired and used to estimate flow rates based on stage for the GFZ and FFZ (Franklin *et al.* 1992, Franklin *et al.* 2000).

Observed flow rates varied from 20% - 35% greater than the standard rating curves. In the range of stage in which most runoff volumes occurred (15 cm to 45 cm) the average difference was about 30 percent. Based on these results, flow rates for the tobacco field flumes were also adjusted upward by 30%.

FIELD AND LABORATORY DATA

BMP Evaluation

To evaluate BMP effectiveness, runoff volumes and concentrations (nutrients and sediment) were measured at three locations: (1) at field edge above the GFZ; (2) at woodland edge above the FFZ; (3) at the lower end of the FFZ (Figure 1).

To evaluate BMPs, runoff volumes, flow rate, time to peak flow, sediment and nutrient concentrations were measured:

1. Between treatment plots for tillage practices, over the two replications.
2. Above and below GFZs.
3. Above and below FFZs.
4. Between current (clear cut) and prior (mature woodland) performance of the FFZ in Watershed I.

Sample Collection and Analysis

Discrete 500 ml sample bottles were collected within 12 to 24 hours (shorter intervals during hot weather), placed on ice in coolers in the field, and then refrigerated in the lab until analyzed. For most events, average concentrations and total loadings for the event at each flume were computed by mixing a single 500 ml flow-proportional aliquot for each flume. This was done by compositing the samples in the lab from hydrographs at each flume. For a subset of events, each discrete sample was analyzed for concentrations of sediments and nutrients.

In preparation for analyses, samples were shaken and split into two portions: 250 ml for total suspended solids (TSS) analysis, and 250 ml for nutrient analysis.

Standardized analytical procedures were used as follows:

<u>Total Suspended Solids (TSS)</u>: Method 160.2 (Gravimetric, dried at 103-105°C) for non-filterable residues. <u>Methods for Chemical Analysis of Water and Wastes</u>. 1979.

<u>Nitrate Nitrogen (NO_3-N)</u>: Method 353.2. Ref: USEPA. 1993. *Methods for the Determination of Inorganic Substances in Environmental Samples.* EPA/600/R-93/100. Environmental Monitoring and Support Laboratory, USEPA, Cincinnati, Ohio. (limit of quantification - 0..05 mg/l).

<u>Ammoniacal Nitrogen (NH_4-N)</u>: Method 350.1. Ref: USEPA. 1993. *Methods for the Determination of Inorganic Substances in Environmental Samples.* EPA/600/R-93/100. Environmental Monitoring and Support Laboratory, USEPA, Cincinnati, Ohio. (limit of quantification - 0..05 mg/l).

<u>Total Kjeldahl Nitrogen (TKN)</u>: Method 351.2. Ref: USEPA. 1993. *Methods for the Determination of Inorganic Substances in Environmental Samples.* EPA/600/R-93/100.

Environmental Monitoring and Support Laboratory, USEPA, Cincinnati, Ohio. (limit of quantification - 0.1 mg/l).

Ortho-phosphate (OP): Method 365.1. Ref: USEPA. 1993. *Methods for the Determination of Inorganic Substances in Environmental Samples.* EPA/600/R-93/100. Environmental Monitoring and Support Laboratory, USEPA, Cincinnati, Ohio. (limit of quantification - 0.01 mg P/l).

Total Phosphate (TP): Method 365.1. Ref: USEPA. 1993. *Methods for the Determination of Inorganic Substances in Environmental Samples.* EPA/600/R-93/100. Environmental Monitoring and Support Laboratory, USEPA, Cincinnati, Ohio. (limit of quantification - 0.05 mg P/l).

CULTIVATION ACTIVITIES AND OBSERVATIONS

All fields were disked, fumigated, and bedded in fall 1998. Bed tops were flattened and winter rye grass was sown and fertilized in late October. The rye on the conservation tillage was treated with two applications of Gramoxone herbicide on May 7 and 8 to kill the winter cover. Two treatments were required to fully kill the crop which averaged four to five feet in height. The rye crop was moderate on row tops and extremely thick in furrows. In early May, the conventional tillage fields were cross disked to incorporate the winter rye cover into the soil and to allow the rye to begin decomposition to minimize problems for the tobacco transplanter. After several weeks, the CT fields were rebedded.

In May, grass on all waterways was thickened by over-seeding with coastal Bermuda grass. Existing grass cover was moderate and consisted of a mixture of fescue, sudan grass, and a minor amount of coastal Bermuda grass.

All fields were planted with tobacco on May 20.. A modified transplanter on loan from Cooperative Extension was used all fields. The shank was lengthened to provide a deeper slit for the greenhouse plants normally used on Cooperative Extension demonstration projects with private farmers. Previous projects with private farmers had indicated that deeper planting provided better survival with greenhouse-grown plants. However, nursery plants are still grown at Oxford and were used. Planting occurred after several dry weeks. Approximately thirty percent of transplanted tobacco appeared to have died several days after transplanting. An irrigation system was installed and used about five days after planting. Dead tobacco was replanted by hand each of the two succeeding weeks after planting.

Throughout the tobacco growing season, many of the plants were somewhat dwarfed compared with normal size at given times. Most plants began ripening about a month early. Our preliminary conclusions are that (1) plant mortality was caused by the use of the less thrifty bed-grown plantlets used with the modified transplanter which is normally used with greenhouse-grown plantlets. We additionally believe that by aggressively irrigating the plants shortly after transplanting to improve survival, we leached most of the fertilizer from the root zone resulting in the smaller plants and early ripening. Ground cover on the NT treatments remained excellent throughout the season. Weed competition was not significant on any fields, regardless of tillage treatment.

PERFORMANCE OF WATER SAMPLING SYSTEM

This report summarizes results of two separately funded one-year projects. Although the two projects spanned two tobacco growing seasons, neither project covered 12 months of monitoring in any one year. There was additionally a brief funding gap between projects. The initial data collection period began December 15, 1998 and ended September 16, 1999. Three of the last four events prior to shut-down were tropical storms (Dennis twice and Floyd) as they passed through Granville County. No runoff events were collected for the 1999-2000 winter rye cover crop. The collection system was reactivated April 1, 2000 with new funding and then shut down on December 17, 2000. The resulting periods for which runoff data were obtained included the periods 12/16/98 to 9/15/99 and 5/27/00 to 12/16/00 for a total of 40 rainfall-producing events. Many of these events did not generate enough rainfall to submerge water sampler intake ports. Instrument failures further reduced the number of events usable for analyses to 30 (Table 2).

Causes of failures included transient voltage due to electrical storms and animal damage. These data included eight events during the 1999 winter cover crop, four during the 1999 tobacco cultivation season, 17 during the 2000 tobacco cultivation season, and a single event on December 16, 2000 while fescue was being established as the winter cover crop. Causes of failures included transient voltage due to electrical storms and animal damage.

Table 2. Number of events successfully collected and used and operational date ranges

Type of evaluation	Number of events used	Operational dates
Winter rye grass cover crop	8	12/16/98 - 04/11/99
Tobacco tillage system comparison	4	04/18/99 - 09/15/99
	17	05/27/00 - 09/25/00
Single large event on winter fescue cover crop	1	12/16/00
Total events for current study	**30**	
Clear cut forested filter zone vs	30 (current study)	12/16/98 - 12/16/00
Mature forested filter zone	47 (former study)	10/02/89 – 03/08/95

RESULTS AND DISCUSSION

EFFECTIVENESS OF NO-TILL, GRASSED AND FORESTED FILTER ZONES

Infiltration

No-Till. No clear trend emerged with respect to infiltration differences between tobacco tillage treatments although CT had a slightly higher rate in three of the four comparisons (Table 3). Crop fields in both watersheds infiltrated well during the 1999 cover crop season with infiltration rates of 60 and 69 percent. During the single large event of December 2000, infiltration rates were much lower (Table 4).

Grassed Filter Zones. Infiltration rates in the GFZs were generally very low to negative during the tobacco and cover crop seasons in both years (Tables 3 and 4). The only exception was the GFZ in WS I in 1999 which showed an infiltration rate of 43% (Table 4). The GFZ in WS I consistently had higher rates of infiltration than the GFZ in WS II. Several physical features of the GFZ in WS II were not favorable for filter zone function. The flow path through the GFZ below the NT field waterway was narrow because of topography. Also on WS II, the lower end of the CT waterway was less than 10 m up-slope from the receiving FFZ flume and much of that flow path was compacted from frequent vehicle traffic. Thus, only a portion of the 0.12 ha of potential GFZ (Table 1) received direct contact from surface runoff and infiltration on the vehicle path was probably poor due to compaction. The size and topography of the more effective GFZ on WS I was much more characteristic of GFZs available on most farms.

During all periods except the cover crop season of 1999 in WS I, infiltration was low or negative for GFZs in both watersheds indicating that the volume of runoff leaving the zone was about equal to the estimated sum of rainfall plus runoff entering the GFZ. Indications were that infiltration in GFZs was effective during events of low intensity, but ineffective during events of high intensity, even for the adequately sized GFZ in WS I (Tables 3 and 4).

Forested Filter Zones. Infiltration in the FFZs averaged 56%, with the densely vegetated (previously clear cut) WS I doing substantially better than WS II with the mature mixed pine-hardwood forest. So the FFZs and the fields infiltrated rainfall at about the same rate, a rate which was five times that of the GFZs. (Table 3). Averages were fairly similar for the cover crop seasons, but the two individual seasons were quite different. Infiltration was generally quite high for the 1999 season, and generally low, with the exception of the forested zone, for the December 16, 2000 event (Table 4).

Peak Flow Rates

No-Till. No clear trend in peak flow (m^3/hr) differences emerged between tillage treatments for the four largest rainfall events during each crop year. Peak runoff differences between CT and NT fields were within 15% of each other, with two rates higher for CT and two higher for NT (Table 5). During the cover crop season of 1999, peak flow rates were slightly lower than those for the tobacco crop the same year. Peak flow rates during the December 16, 2000 event were

Table 3. Infiltration of rainfall and runoff in tobacco fields, grassed filter zones (GFZs), and forested filter zones (FFZs) during the tobacco growing seasons of 1999 and 2000

	Fields			GFZ			FFZ		
	Rainfall (mm)	Infiltration (mm)	Percent Infiltrated (%)	Rainfall plus Runoff (mm)	Infiltration (mm)	Percent Infiltrated (%)	Rainfall plus Runoff (mm)	Infiltration (mm)	Percent Infiltrated (%)
1999									
Watershed I	310								
Conventional Tillage		115	37%	--	--	--	--	--	--
No-Till		148	48%	--	--	--	--	--	--
Filter Zones				1,577	166	11%	1,524	965	63%
Watershed II	310								
Conventional Tillage		216	70%	--	--	--	--	--	--
No-Till		153	49%	--	--	--	--	--	--
Filter Zones				1,392	-230	-17%	938	328	35%
2000									
Watershed I	272								
Conventional Tillage		134	49%	--	--	--	--	--	--
No-Till		99	36%	--	--	--	--	--	--
Filter Zones				1,365	377	28%	1,123	798	71%
Watershed II	272								
Conventional Tillage		183	67%	--	--	--	--	--	--
No-Till		152	56%	--	--	--	--	--	--
Filter Zones				1,165	139	12%	670	354	53%
Means			**52%**			**9%**			**56%**

Table 4. Infiltration of rainfall and runoff in cover crop fields, grassed filter zones (GFZs), and forested filter zones (FFZs) during the cover crop seasons of 1999 and a single event in December 2000

	Fields			GFZ			FFZ		
	Rainfall (mm)	Infiltration (mm)	Percent Infiltrated (%)	Rainfall plus Runoff (mm)	Infiltration (mm)	Percent Infiltrated (%)	Rainfall plus Runoff (mm)	Infiltration (mm)	Percent Infiltrated (%)
1999									
Watershed I	210	125	60	807	346	43	606	310	51
Watershed II	210	145	69	761	- 49	- 6	523	320	61
December 2000									
Single event									
Watershed I	34	4	12	246	25	10	225	143	64
Watershed II	34	11	32	230	- 2	- 1	124	64	51
Means			43%			12%			57%

Table 5. Peak flow rates for the four largest rainfall events per crop season and the single largest event in the two-year study period (December 2000) for fields in tobacco and winter cover crops, for grassed filter zones (GFZs), and forested filter zones (FFZs) in 1999 and 2000

	Total Rainfall	Peak Runoff		
1999	(mm)	Fields (m^3/hr)	GFZ (m^3/hr)	FFZ (m^3/hr)
Watershed I				
Winter Cover Crop	37	91	71	59
Tobacco	77			
Conventional Tillage		99	--	--
No-Till		86	--	--
Filter Zones			209	48
Watershed II				
Winter Cover Crop	37	64	77	48
Tobacco	77			
Conventional Tillage		77	--	--
No-Till		86	--	--
Filter Zones			203	96
2000				
Watershed I				
Tobacco	30			
Conventional Tillage		71	--	--
No-Till		79	--	--
Filter Zones			184	72
December 2000 Single rainfall event	34	559	704	288
Watershed II				
Tobacco	30			
Conventional Tillage		111	--	--
No-Till		93	--	--
Filter Zones			191	123
December 2000 Single rainfall event	34	546	459	252

five times the highest rates observed for the highest tobacco crop field (WS II, CT) (Table 5).

Grassed Filter Zones. Peak flows rates in both GFZs were generally equal to or substantially higher than the sum of rates for respective contributing fields. Peak flow rates in GFZs were two to four times higher than those at the lower ends of the respective FFZs. These results are consistent with the low infiltration rates observed (Table 5).

Forested Filter Zones. Peak flow rates at the lower end of the FFZs during the tobacco crop season were generally about half the flow rates at the upper end as water was leaving the GFZs. This is consistent with the generally high rates of infiltration observed in the FFZs. There was less difference between GFZs and FFZs during the low flow events of the 1999 cover crop season. During the large event of December, 2000, peak flow rates from the FFZs were 40% to 55% of those from the GFZs (Table 5).

Total Suspended Solids

No-Till. TSS (kilograms per hectare of source area) lost from fields in surface runoff during the tobacco tillage season was 70 to 90 percent less from NT compared to CT, varying slightly by year and watershed. The highest observed rate of loss was 1098 kg/ha for CT in WS II in the 2000 tobacco crop season. The paired NT field lost only 131 kg/ha, a reduction of 88% (Table 6). Other researchers reported similar sediment loss reductions with various forms of conservation tillage (Angle *et al.* 1984, Johnson *et al.* 1979, McDowell and McGregor 1980, Mostaghimi *et al.* 1991, Smith *et al.* 1995).

Table 6. Gravimetric loadings for total suspended solids (TSS) for conventional tillage (CT) and no-till (NT) tobacco crops, and percent reductions as a result of the NT practice for four rainfall events in 1999 and 17 rainfall events in 2000

		CT (a) (kg/ha)	NT (b) (kg/ha)	Percent Reduction (a-b)/a*100 (%)
1999				
	WS I	520	134	74
	WS II	544	52	90
2000				
	WS I	781	235	70
	WS II	1,098	131	88

Grassed Filter Zones. The larger, more typically sized GFZ in WS I detained 29% of TSS received from tobacco fields (Table 7) and 55% of TSS during the cover crop season of 1998-99 (Table 8). During the large event of December 16, 2000, the GFZ in WS I detained only 2% TSS (Table 9). The undersized GFZ in WS II actually exported 26% more TSS than it received from tobacco fields (Table 7), and detained only 4% of TSS received during the cover crop season of 1998-99 (Table 8). During the large event of December 16, 2000, the GFZ in WS II exported 14% more TSS than it received from the cover crop fields (Table 9).

Forested Filter Zones. The FFZs detained between 63% and 83% of TSS during the tobacco crop seasons. The GFZs in combination with the FFZs detained from 63% to 88% of all TSS moving through the filter zones during the tobacco crop season (Table 8). During the 1999 cover crop season FFZs detained from 44% to 67% of TSS (Table 9). During the December 16, 2000 event, the FFZs detained from 42% to 58% of TSS. Although this detention rate was somewhat lower than the average for the other crop seasons, it was still impressive when one considered that the December 16, 2000 event delivered substantially more sediment than the total from all other events monitored over the entire two-year study period (Table 9).

Sediments Summary. The 70% to 90% of sediment reduction resulting from no-till compared to conventional tillage, corroborated by many other studies, points conclusively to varying forms of conservation tillage as the most effective solution to tillage sediment discharge problems in agriculture. Issues related to potentially lower yields and nutrient issues must be addressed.

The GFZs in this study were good examples of a reasonably adequate GFZ in WS I, and totally inadequate GFZ in WS II. Sediment was by far the largest contributing pollutant measured in this study and therefore deserved closer study. So we bar-graphed the retention of TSS by GFZ and FFZ for each event monitored to look for seasonal patterns in retention and contrast the adequately sized zone of WS I versus the undersized zone of WS II. The general pattern observed was that through the spring and summer the grassed zones tended to load up with sediment. Then when a large rainfall event occurred, such as on Julian Day (JD) 237, 1999 (Hurricane Dennis), the GFZ in WS I retained very little sediment compared to the FFZ (Figure 2), and the GFZ in WS II exported a large amount of sediment to the FFZ (Figure 2). Having been scoured of sediment on JD237, the GFZ in WS I retained about as much sediment as the FFZ when Dennis returned on JD247 (Figure 2), and the GFZ in WS II exported only a minor amount of TSS to the FFZ (Figure 3). When Hurricane Floyd arrived on JD258, both thoroughly flushed GFZs zones retained substantially more sediment than their respective FFZs. (Figures 2 and 3). Another pattern was that when a GFZ has good sediment capacity for a particular event, even a relatively large event, it will typically retain much more sediment than the FFZ presumably because it gets first crack at the heaviest, most easily retained fractions. This may also explain why a GFZ, especially an undersized one, fills beyond capacity rather rapidly during the tillage season.

The spring and summer of 2000 showed similar patterns. The GFZ in WS I on JD148 and JD171 performed extremely well, but by JD216 and JD217 exported large quantities of TSS to the FFZ during rainfall events substantially less large than the one on JD171 (Figure 3).

Table 7. Gravimetric loadings and percent detained or exported by grassed filter zones (GFZs) and forested filter zones (FFZs) during the 1999 and 2000 tobacco cultivation seasons on Watershed I (WS I) and Watershed II (WS II) in 21 runoff events for total suspended solids (TSS), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (OP), and total phosphorus (TP)

	Fields	GFZs		FFZ		GFZ and/or FFZ	
	leaving fields, entering GFZ (kg/ha)	detained by GFZ (kg/ha)	percent from fields detained (%)	detained by FFZ (kg/ha)	percent from GFZ detained (%)	total detained (kg/ha)	percent from fields detained (%)
TOTAL SUSPENDED SOLIDS							
WS I	853	250	29	498	83	747	88
WS II	862	-222*	-26	682	63	460	63
NUTRIENTS							
NH_4-N							
WS I	0.40	-0.19	-48	0.38	65	0.19	65
WS II	0.31	0.01	3	0.10	34	0.11	36
NO_3-N							
WS I	2.79	0.28	10	1.38	55	1.66	59
WS II	2.09	-0.95	-45	2.05	68	1.10	68
TKN							
WS I	4.51	0.06	1	2.89	65	2.95	65
WS II	3.25	-0.77	-24	1.27	32	0.50	32
OP							
WS I	3.43	0.39	11	2.33	77	2.73	80
WS II	2.37	-0.28	-12	1.44	54	1.16	54
TP							
WS I	4.94	1.73	30	2.84	71	4.57	80
WS II	3.20	-0.96	-30	2.49	60	1.54	60
MEANS (nutrients)							
WS I			1		67		70
WS II			-20		50		50

*A negative number indicates more of the analyte left the GFZ than entered.

Table 8. Gravimetric loadings and percent detained or exported by grassed filter zones (GFZs) and forested filter zones (FFZs) during the 1998 and 1999 winter cover crop on Watershed I (WS I) and Watershed II (WS II) in eight runoff events for total suspended solids (TSS), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (OP), and total phosphorus (TP)

	Fields	GFZs		FFZ		GFZ and/or FFZ	
	leaving fields entering GFZ (kg/ha)	detained by GFZ (kg/ha)	percent from fields detained (%)	detained by FFZ (kg/ha)	percent from GFZ detained (%)	total detained (kg/ha)	percent from fields detained (%)
TOTAL SUSPENDED SOLIDS							
WS I	201	110	55	62	67	171	85
WS II	77	6	6	32	44	37	48
NUTRIENTS							
NH_4-N							
WS I	0.14	0.06	43	0.04	50	0.10	72
WS II	0.14	0.03	23	0.06	55	0.09	65
NO_3-N							
WS I	0.11	0.03	31	0.00	0	0.03	31
WS II	0.15	0.04	24	0.06	51	0.10	63
TKN							
WS I	0.89	0.23	26	0.32	48	0.55	62
WS II	0.78	-0.08*	-11	0.40	46	0.31	46
OP							
WS I	0.40	0.11	24	0.16	53	0.26	64
WS II	0.28	-0.02	-8	0.17	56	0.15	56
TP							
WS I	0.65	0.19	29	0.27	57	0.46	70
WS II	0.39	-0.04	-10	0.25	57	0.21	57
MEANS (nutrients)							
WS I			31		42		60
WS II			4		53		57

*A negative number indicates more of the analyte left the GFZ than entered.

Table 9. Gravimetric loadings and percent detained or exported by grassed filter zones (GFZs) and forested filter zones (FFZs) during the December 17, 2000 rainfall event while fields were in a germinating winter fescue cover crop on Watershed I (WS I) and Watershed II (WS II) in runoff events for total suspended solids (TSS), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), orthophosphorus (OP), and total phosphorus (TP)

	Fields	GFZs		FFZ		GFZ and/or FFZ	
	leaving fields entering GFZ (kg/ha)	detained by GFZ (kg/ha)	percent from fields detained (%)	detained by FFZ (kg/ha)	percent from GFZ detained (%)	total detained (kg/ha)	percent from fields detained (%)
TOTAL SUSPENDED SOLIDS							
WS I	1,427	23	2	591	42	614	43
WS II	1,354	-1,396*	-103	1,590	58	193	58
NUTRIENTS							
NH_4-N							
WS I	0.67	0.53	79	0.11	75	0.64	95
WS II	0.58	0.23	41	0.25	74	0.49	85
NO_3-N							
WS I	0.78	-0.15	-19	0.75	80	0.60	80
WS II	0.62	-0.14	-21	0.52	65	0.38	65
TKN							
WS I	1.98	0.88	45	0.78	71	1.66	84
WS II	1.53	0.23	15	0.97	74	1.19	78
OP							
WS I	1.53	0.19	12	0.98	73	1.17	76
WS II	1.10	0.00	0	0.64	58	0.64	58
TP							
WS I	1.77	0.15	9	1.21	75	1.37	77
WS II	1.31	-0.17	-13	0.94	64	0.78	69
MEANS (nutrients)							
WS I			25		75		82
WS II			4		67		71

*A negative number indicates more of the analyte left the GFZ than entered.

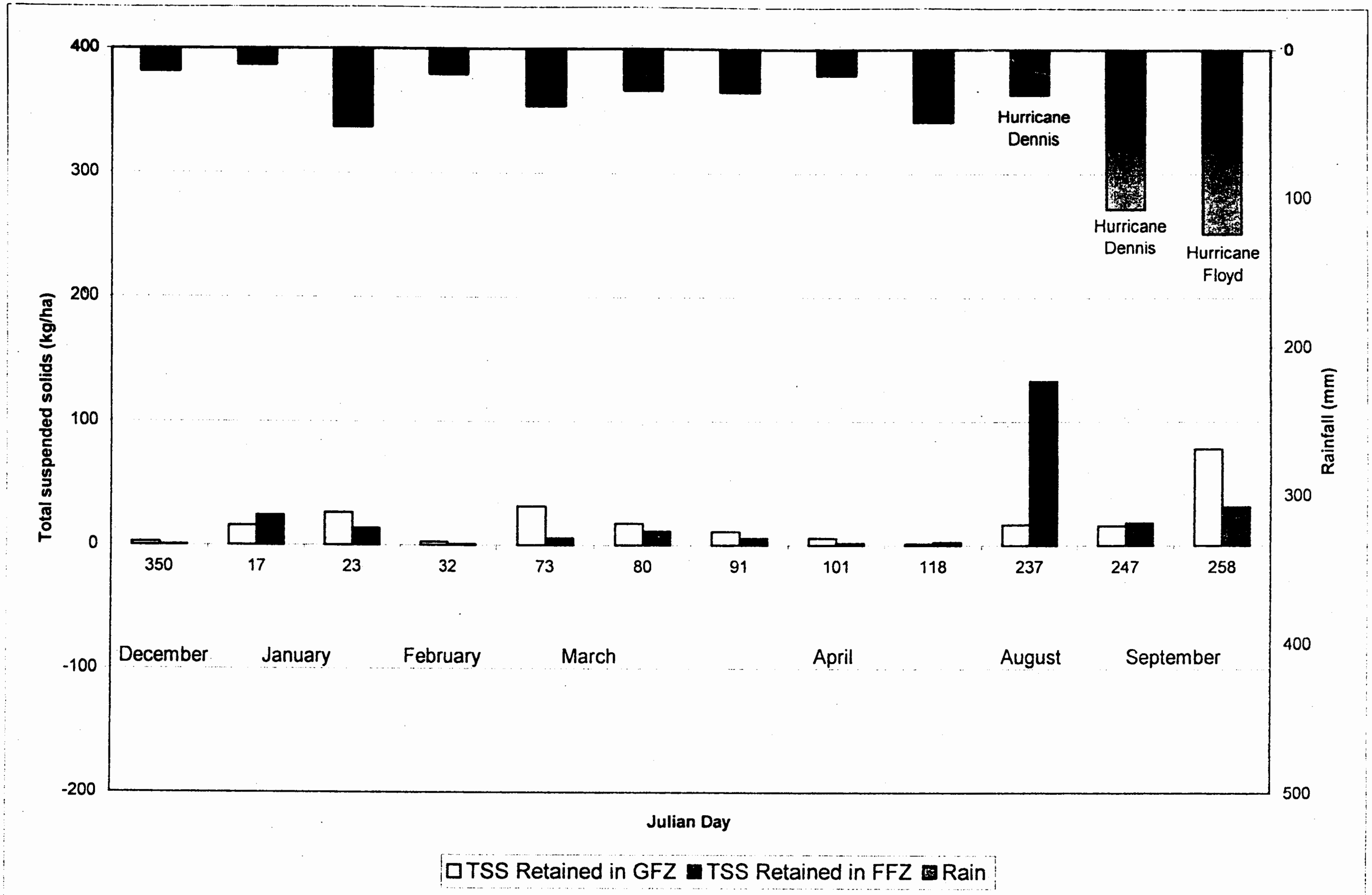


Figure 2. Total suspended solids (TSS) retained in grassed (GFZ) and forested (FFZ) filter zones in Watershed I during December 1998 through September 15, 1999.

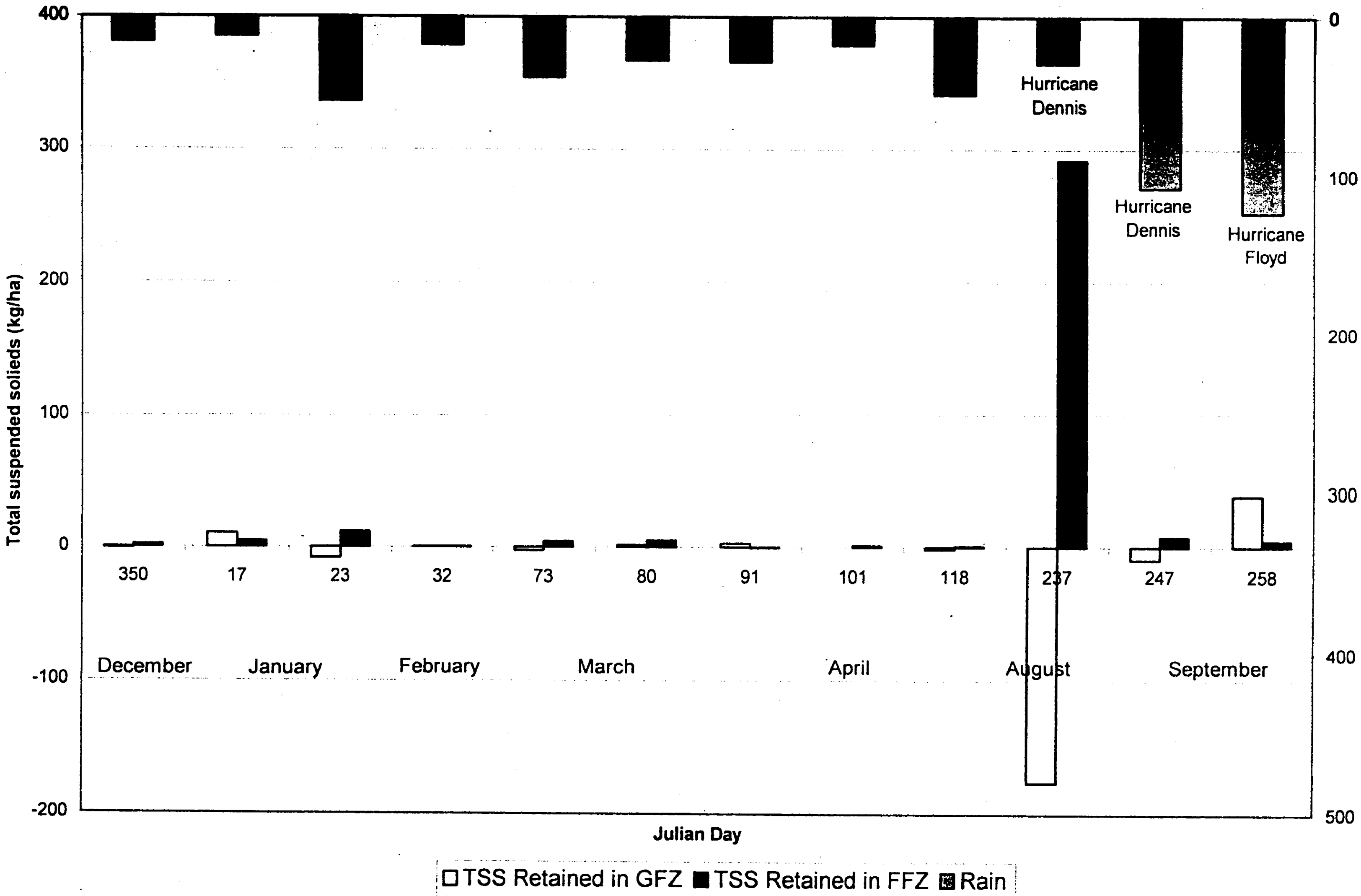


Figure 3. Total suspended solids (TSS) retained in grassed (GFZ) and forested (FFZ) filter zones in Watershed II during December 1998 through September 15, 1999.

Having thus been flushed of sediment, this GFZ continued to detain sediment until JD269 when it again exported a substantial amount of TSS to the FFZ (Figure 4). During the same period of time in 2000, the smaller, undersized GFZ in WS II, showed a continuing series of detention followed by export sequences, with results of the major rainfall events very similar to the GFZ in WS I (Figure 5). To complete the contrasts between GFZs and FFZs, we added the rainfall event of December 16, 2000 (JD351) (Figures 6 and 7). Note that there was no measurable rainfall between JG 269 and JD 351. Having flushed on JD269, the GFZ in WS I retained a very small amount of sediment in this large event. Even though the GFZ in WS II had similarly flushed on JD269, it was completely overwhelmed by the event and exported almost as much as the FFZ detained. Clearly, the typically sized GFZ in WS I was not sufficient by itself to substantially reduce TSS under these conditions, and the small GFZ in WS II was hopelessly undersized.

The FFZs consistently did a good job of sediment detention ranging from a low of 43% to a high of 88% over watersheds and seasons. The FFZ in WS I performed somewhat better than the FFZ in WS II except during the large event of JD351, 2000. The generally higher infiltration capacity of the FFZ in WS II probably explains that difference during such an large event.

Nutrients

No-Till. Nutrient losses were so low that no clear trends in differences could be detected between CT and NT (Appendix Table 2). There was a slight trend toward more total P and N lost from NT fields (Table 10). Others have observed higher nutrient losses from various forms of conservation tillage, especially soluble nutrients, when compared with CT (Angle *et al.* 1984, Andraski *et al.* 1985, Barias *et al.* 1978, Gaynor and Findlay 1995, Johnson *et al.* 1995, McDowell and McGregor 1980, Schreiber and Cullum 1998). Those investigators generally attributed increased losses from conservation tillage to applying unincorporated fertilizer on conservation tillage treatments and to a release of P from crop residue. Ground cover was excellent on NT fields both years in his study, and fertilizer was broadcast rather than incorporated on both treatments.

In summary, most studies of crop tillage systems showed that the principal benefit from conservation tillage was substantially reduced soil loss, as was found in this study.

Grassed Filter Zones. Detention of nutrients by the GFZ in WS I during the tobacco crop season averaged 1%, while detention in WS II was -20% (Table 7). During the cover crop season of 1998-99, the GFZ in WS I detained 31% of nutrients, while the GFZ in WS II detained 4% (Table 8). During the large event on JD351, 2000, the GFZ in WS I detained 25%, while the GFZ in WS II detained 4% (Table 9). Amounts of nutrients leaving tobacco fields was generally low (Table 7), to extremely low during the cover crop season of 1998-99 (Table 8). Amounts of nutrients leaving the fields on the JD351, 2000 were significant, especially for a single event (Table 9). With such low rates of release, performance of filter zones on individual analyts was unreliable, but the average detention rates over all analyts presented a consistent pattern. Nutrient retention by the GFZs followed the pattern of TSS retention wherein the larger GFZ in WS I performed reasonably well during the cover crop seasons and poorly during the tobacco season. The undersized GFZ in WS II detained very little during the cover crop seasons and was a net exporter of nutrients during the tobacco season.

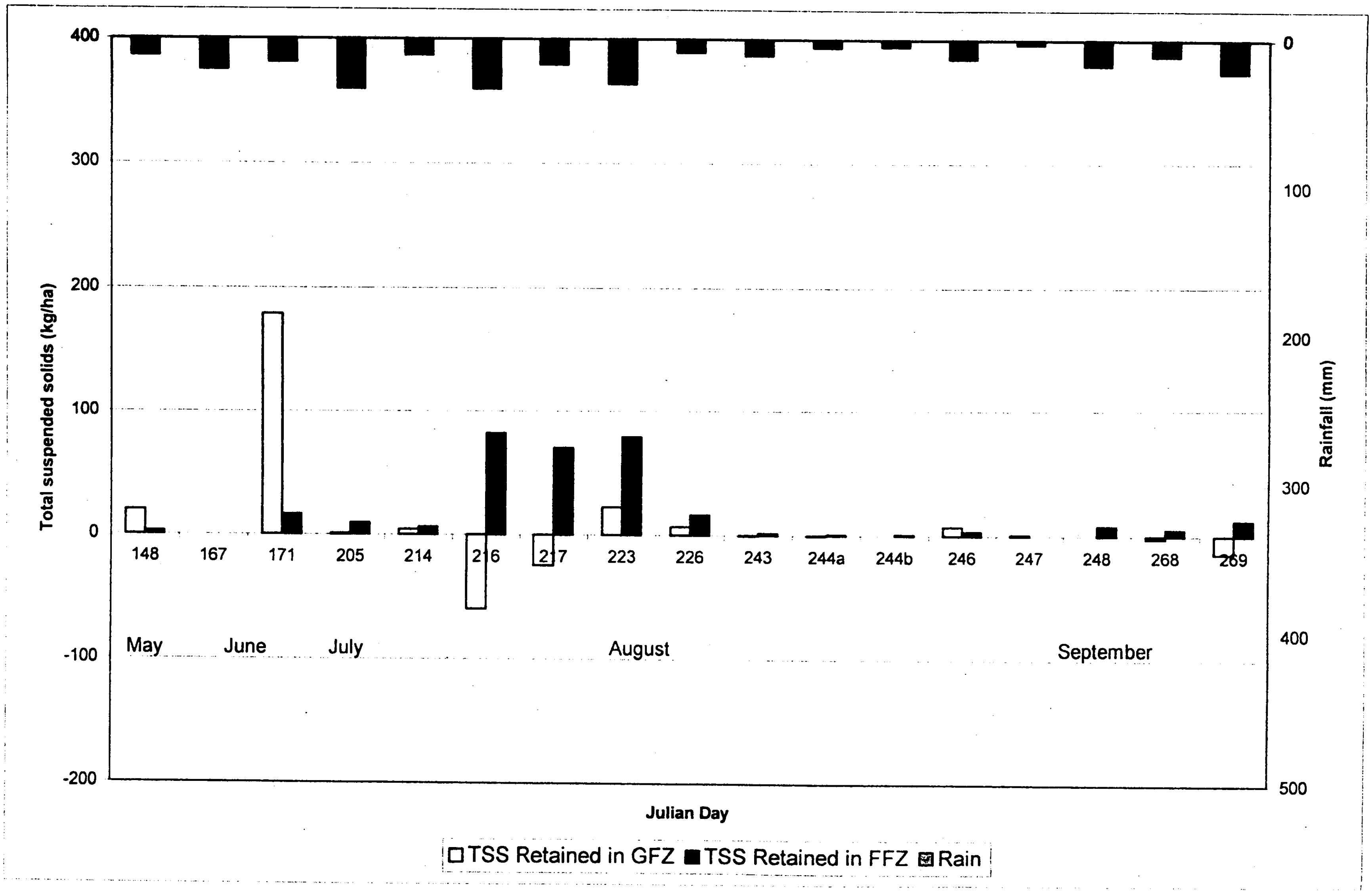


Figure 4. Total suspended solids (TSS) retained in grassed (GFZ) and forested (FFZ) filter zones in Watershed I during May 27, 2000 through September 25, 2000.

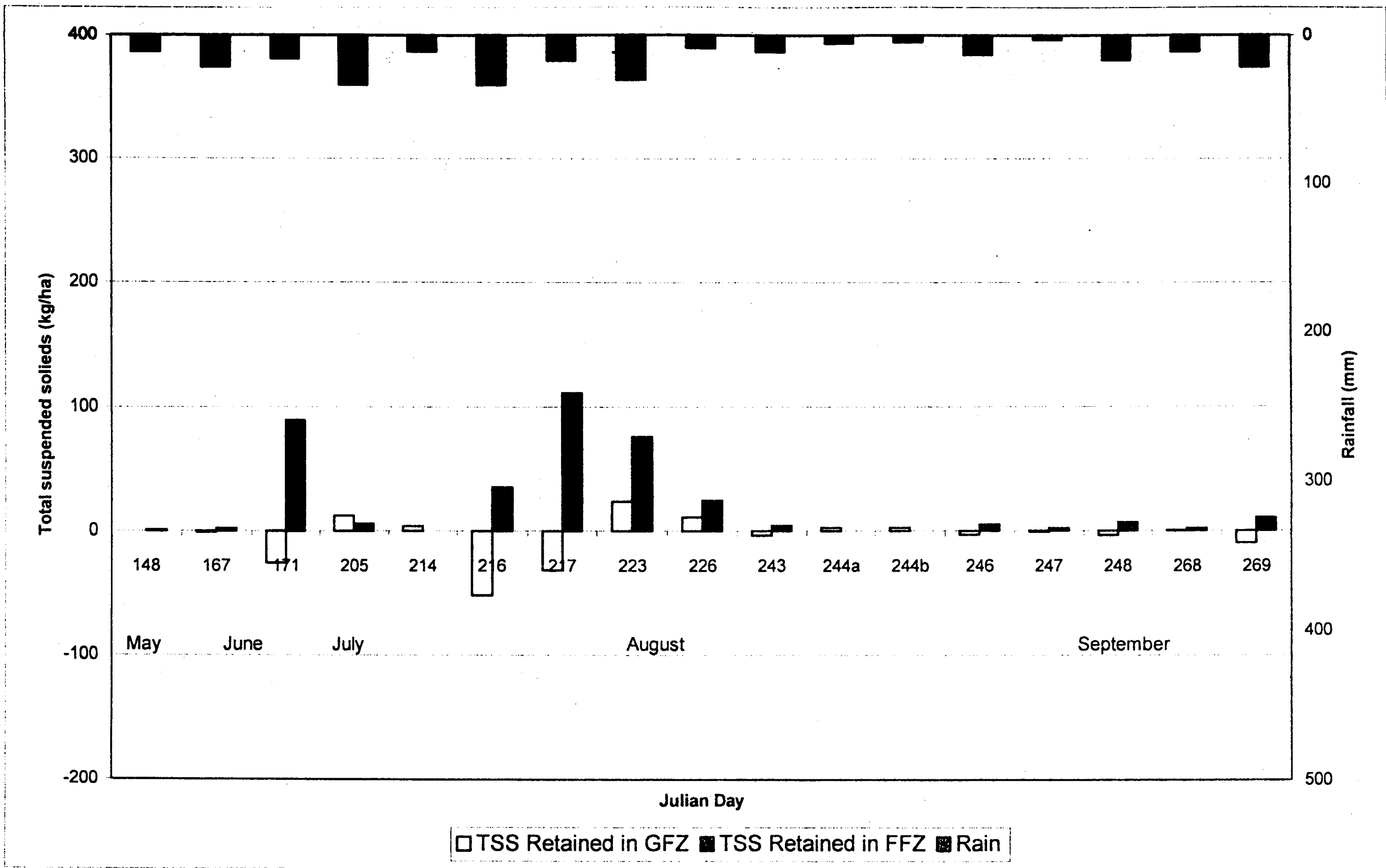


Figure 5. Total suspended solids (TSS) retained in grassed (GFZ) and forested (FFZ) filter zones in Watershed II during May 27, 2000 through September 25, 2000.

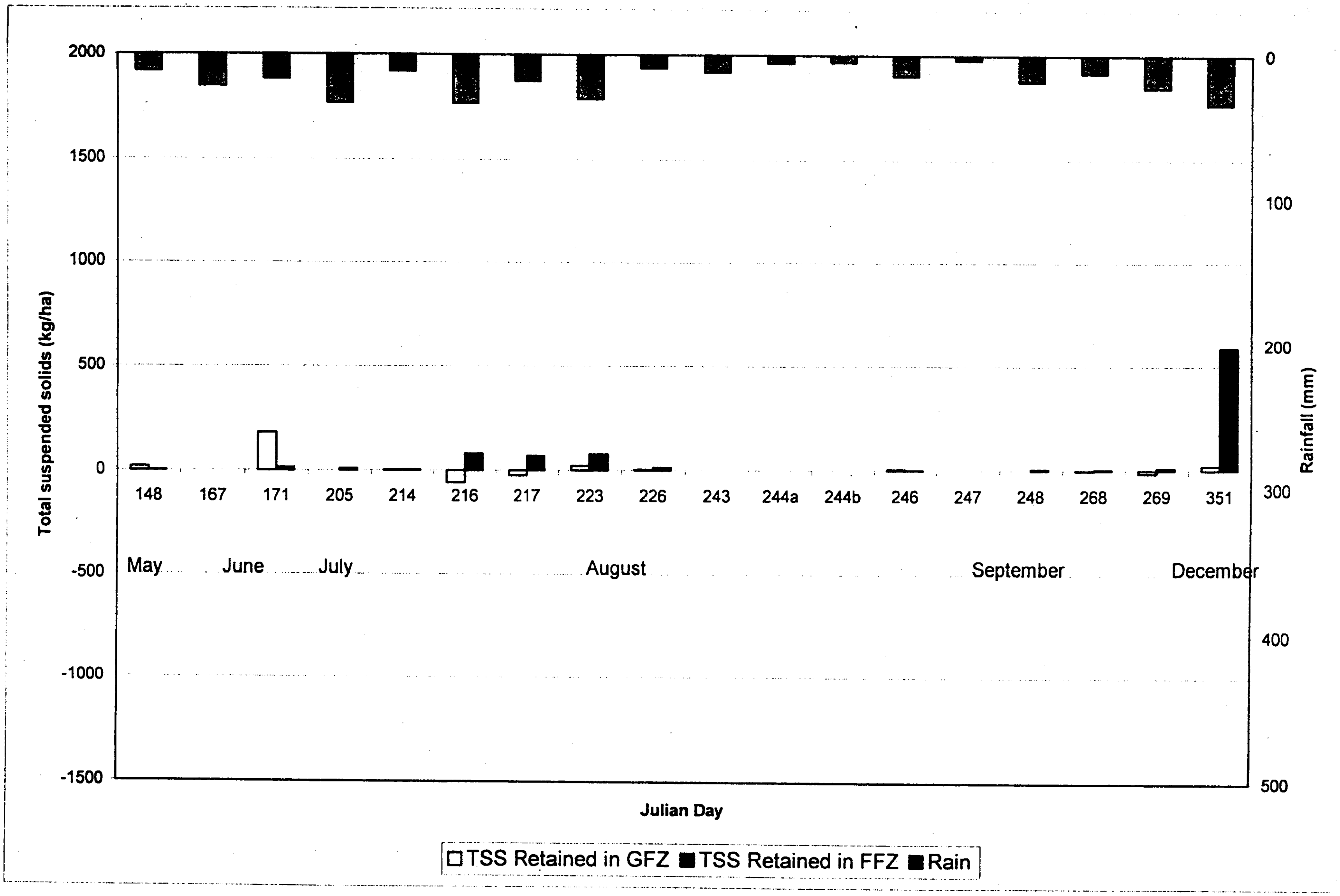


Figure 6. Total suspended solids (TSS) retained in grassed (GFZ) and forested (FFZ) filter zones in Watershed I during May 27, 2000 through December 16, 2000.

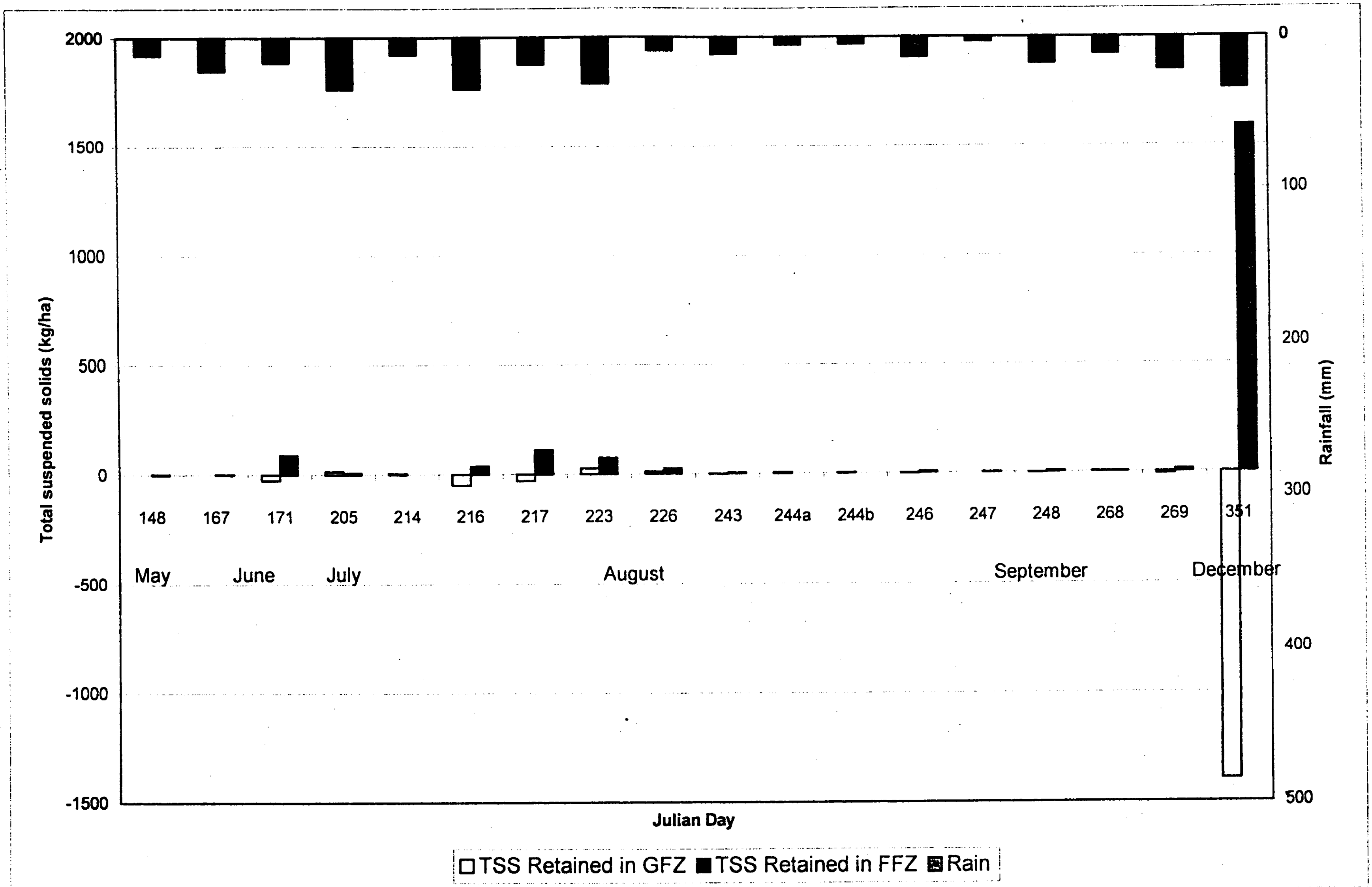


Figure 7. Total suspended solids (TSS) retained in grassed (GFZ) and forested (FFZ) filter zones in Watershed II during May 27, 2000 through December 16, 2000.

Table 10. Gravimetric loadings of nutrients and differences between conventional tillage tobacco (CT) fields and no-till tobacco (NT) fields for four and seventeen runoff events in 1999 and 2000 respectively, for ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (OP), and total phosphorus (TP) in Watershed I (WS I) and Watershed II (WS II)

		CT (a) (kg/ha)	NT (b) (kg/ha)	difference (a-b) (kg/ha)
NH_4-N				
1999	**WS I**	0.19	0.17	0.02
	WS II	0.09	0.16	-0.07
2000	**WS I**	0.16	0.28	-0.12
	WS II	0.19	0.17	0.02
NO_3-N				
1999	**WS I**	0.55	0.13	0.42
	WS II	0.31	0.35	-0.04
2000	**WS I**	1.77	3.00	-1.23
	WS II	0.80	2.58	-1.78
TKN				
1999	**WS I**	1.51	1.63	-0.12
	WS II	0.57	1.39	-0.82
2000	**WS I**	2.22	3.73	-1.51
	WS II	1.74	2.69	-0.95
OP				
1999	**WS I**	1.84	1.81	0.04
	WS II	0.78	1.98	-1.20
2000	**WS II**	1.32	1.91	-0.59
	WS II	0.53	1.32	-0.79
TP				
1999	**WS I**	4.44	2.20	2.24
	WS II	0.90	2.26	-1.36
2000	**WS I**	2.00	2.74	-0.74
	WS II	1.10	1.98	-0.88

Forested Filter Zones. The FFZs detained on average from 50% to 67% of all nutrients received from the GFZs during the tobacco season (Table 7). The combination of GFZs and FFZs generally detained from 50% to 70% of all nutrients received from the tobacco fields. During the 1998-99 cover crop season, detention rates were similarly high averaging 42% to 53% for FFZs and 57% to 60% for the combination of GFZs and FFZs.(Table 8). During the JD351, 2000 event, FFZs detained nutrients at rates of 67% to 75%, and the combination of GFZs and FFZs detained nutrients at rates of 71% to 82% (Table 9) This was exceptionally good performance by these filter zones considering the intensity of the rainfall event, although total amounts of nutrients released was relatively low. Contributing to this good performance was the extremely high infiltration capacity of the FFZs which resulted from the almost total absence of rainfall during the entire fall of 2000.

VEGETATION MANAGEMENT IN AN FFZ

During earlier studies of the same watersheds and FFZs (1989-94), the WS I FFZ performed rather poorly in removing nutrients removing as little as 4% of NO_3-N up to about 42% of NH_4-N (Franklin *et al.* 2000). With vegetation resulting from clear cutting of the overstory in this FFZ as described above, effectiveness of the zone improved dramatically especially in detention of nutrients (Table 11). Improved performance probably resulted from decreased velocity of runoff and increased detention time due high structural resistance from dense, woody vegetation. This effect would also be expected to provide for higher infiltration and more contact with adsorption surfaces. Previous research demonstrated that performance of GFZs can be greatly improved by installing level spreaders to disperse runoff (Franklin *et al.* 1992, Franklin *et al.* 2000, Hazel 2000). Results of this research indicate that vegetation management in FFZs can further improve the ability of these zones to detain pollutants, especially in combination with level spreaders as was done in this research. A heavy thinning of trees would probably be as effective as cutting all the trees as long as enough light reached the forest floor to stimulate plant growth. Low intensity, controlled fires could be used to maintain dense, low vegetation. Mowing would not be preferred because of the resulting compaction of soil. The transition area between GFZs and FFZs can be enhanced by sowing crops such as lespedeza or other crops with closely spaced, stiff, woody stems.

TOBACCO YIELD AND QUALITY

Yield

Yield for NT tobacco were about 32% less than that for CT tobacco in 1999 and about 19% less in 2000. Even so, yields for both NT and CT exceeded the regional average in 2000 by almost 200 kg/ha for NT and by over 800 kg/ha for CT (Table 12). The 1999 crop was especially poor at least in part for the following reasons. Use of small, bed-grown planlets and a modified no-till transplanter in 1999 that distributed water below the root zone of the small plantlets resulted in poor initial survival. After spot replanting, fields were intensively irrigated to improve survival. However, irrigation may have excessively leached nitrogen from the soil. The combination of late replanting and possible N leaching probably accounts for the low yields for both NT and CT treatments in 1999. However, in both years, it may be assumed that these factors impacted both treatments equally, thus, yields from NT tobacco as done in this study may be expected to be lower than those for CT.

Quality

Tobacco quality, based on price/quality index published for tobacco research, was lower in both years for NT compared to CT. Similarly, average grade for CT and NT was lower than the regional average grade (Table 12).

Table 11. Reductions in total suspended solids (TSS), ammoniacal nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total Kjeldahl nitrogen (TKN), ortho-phosphorus (OP), and total phosphorus (TP) for a forested filter zone before and after clear cutting

	mature forest* (%)	clearcut** (%)
TSS	46	51
NH_4-N	48	76
NO_3-N	15	78
TKN	25	73
OP	33	77
TP	23	78
Means	32	72

* October 1989 – April 1995 (47 events)

** December 1998 - September 2000 (30 events)

DESIGNING SYSTEMS FOR LARGE EVENTS

During previous research on the FFZs in WS I and WS II, it was observed that 80 percent or more of TSS and nutrients were delivered to filter zones in three to eight events per year (Franklin *et al.* 2000). These observations indicated that VFZs must be designed to handle the largest events. If nor, most pollutants will reach receiving waters even though VFZs are in place. In the previous research, it was also observed that the percent of pollutants detained during the large events by the two experimental FFZs events was as great or only slighlt less than than that detained for all events combined. The absolute quantities of pollutants detained was almost always larger for the large events, and that was accomplished without excessive damage to the filtration capacity of the zone (Franklin *et al.* 2000). For events in this study, detention of pollutants was calculated for each GFZ and FFZ based on the percent of the total

Table 12. Comparison of tobacco yields and prices by tillage practice in 1999 and 2000

	Yield (kg/ha)	Average Price ($/kg)	Gross Receipts ($/ha)
No-till			
1999	1,542	$ 3.60**	$ 5,559.78
Conventional tillage			
1999	2,257	$ 3.66**	$ 8,259.17
No-till			
2000	2,822	$ 3.61**	$ 10,188.95
Conventional tillage			
2000	3,479	$ 3.65**	$ 12,708.77
Typical regional*			
1999	2,309	$ 3.88	$ 8,958.92
2000	2,628	$ 4.01	$ 10,538.28

*North Carolina Department of Agriculture and Consumer Services, Agricultural Statistics Division – Field Crops, Annual Summary: Crop Estimates, North Carolina, 1998-2000. http://www.ncagr.com/stats/pric_rec/prrtobyr.htm

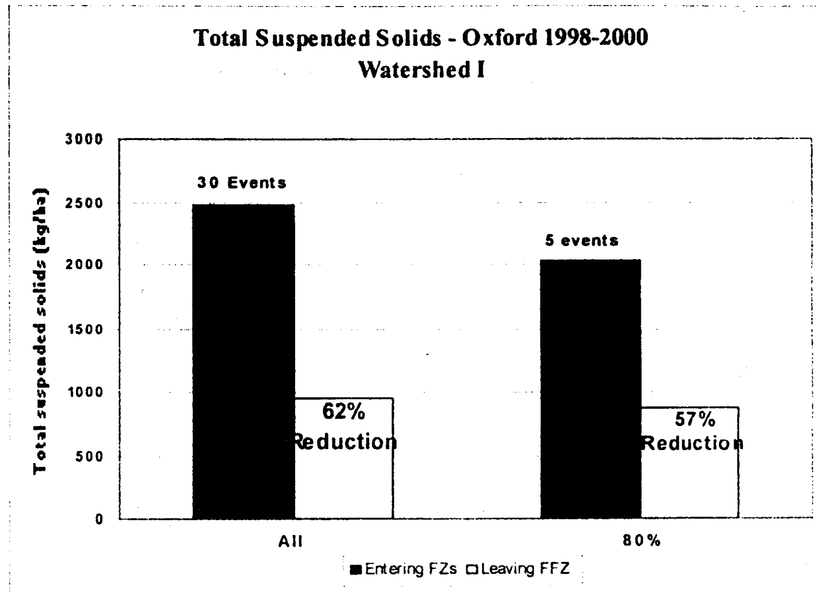
** Based on average price index for 1999 and 2000 by the Official Variety Testing Program, Crop Science Department, North Carolina State University.

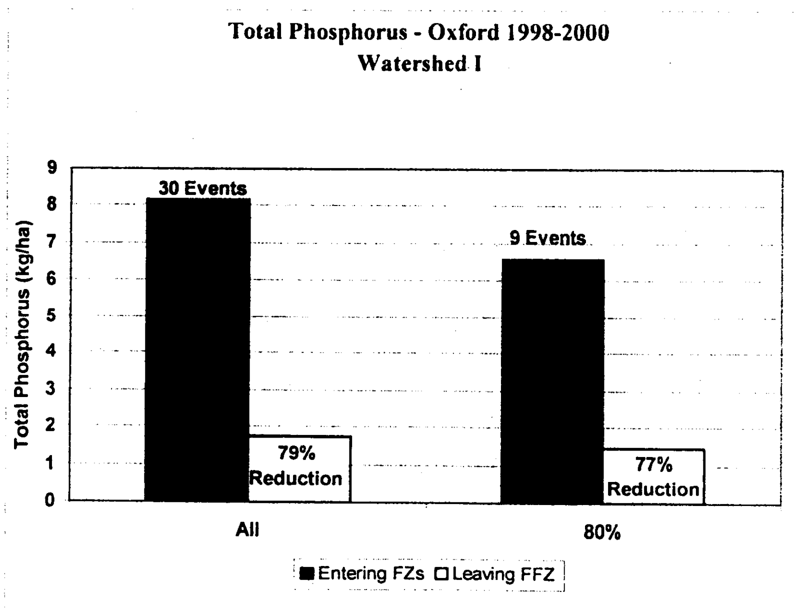
gravimetric loading detained (total input minus total output as a percentage of input) for each analyt. Then, percentage detained was calculated for only the largest events that together contributed about 80 percent of the total of all events for the analyt (referred to as "80 percent events"). In all cases, if the GFZ had a net export to the FFZ, then the amount exported to the FFZ was used as the denominator (base) for the percentage reduction for the combined detention percentage (Figures 8 -11), to properly represent the detention percentage in both zones combined. FFZs never had a net export situation, even during the largest events.

For the 30 runoff events monitored in this study during major portions of 1999 and 2000, five to 13 events contributed 80 percent or more of the total gravimetric loading of all analyts. For total suspended solids, the December 16, 2000 event delivered more sediment than the entire sum for all other events monitored. Four additional, much smaller events were required to cover 80% of TSS over the two-year period. Similar patterns were also observed with nutrients (Figures 8-11).

Frequently used design criteria for VFZs include bypass channels to divert the heaviest runoff around the zone, ostensibly to protect the integrity of the zone during large runoff events. However, these data and those of earlier studies demonstrate that these experimental FFZs handle large events very well. Thus, it is illogical to design FFZs so that runoff from major events by-passes the filter zone. These large events are the ones most in need of treatment. If the system fails to effectively handle the large events (including hurricanes and other major events), the system has failed to effectively reduce sediments and nutrients in agricultural runoff reaching receiving waters.

Figure 8. Gravimetric sum of total suspended solids, ortho-phosphorus, and total phosphorus entering the grassed and forested filter zones (FZs) and leaving the forested filter zones (FFZ) from December 16, 1998 to December 16, 2000 on Watershed I for all events and for the largest events contributing about 80 percent of the total for each analyte. Numbers over the "Entering FZs" bar are the number of runoff events. Numbers in front of the other bars are the percent of analytes detained by the FZs.





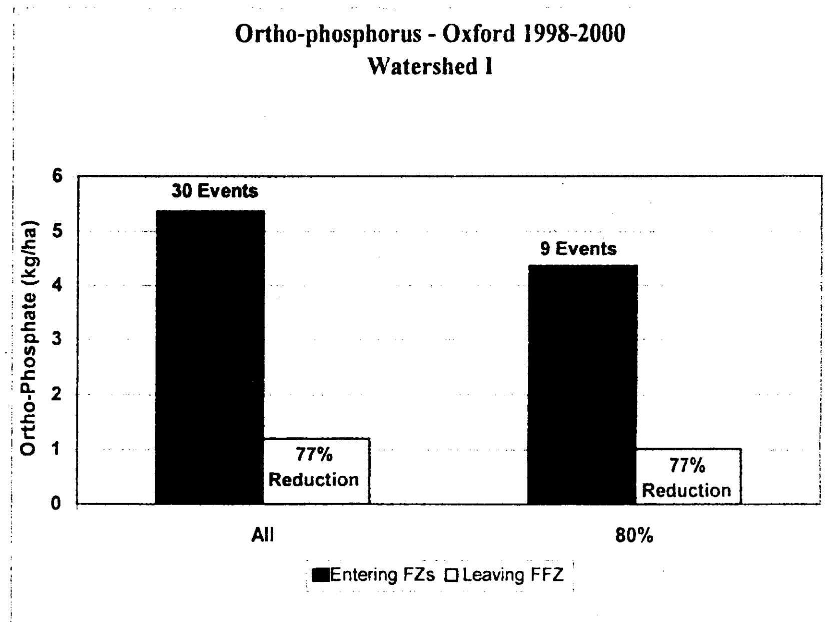
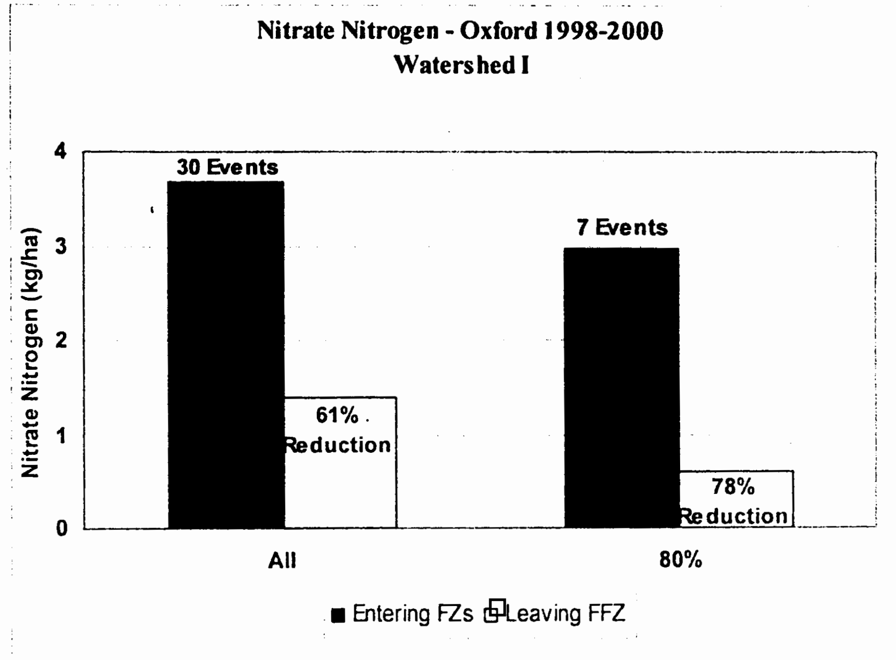
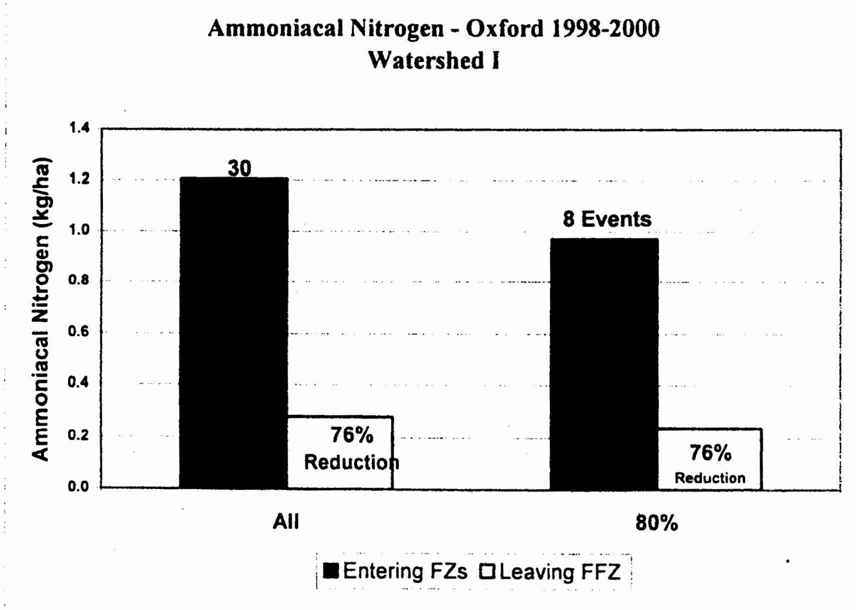


Figure 9. Gravimetric sum of nitrate nitrogen, ammoniacal nitrogen, and total Kjeldahl nitrogen entering the grassed and forested filter zones (FZs) and leaving the forested filter zones (FFZ) from December 16, 1998 to December 16, 2000 on Watershed I for all events and for the largest events contributing about 80 percent of the total for each analyte. Numbers over the "Entering FZs" bar are the number of runoff events. Numbers in front of the other bars are the percent of analytes detained by the FZs.





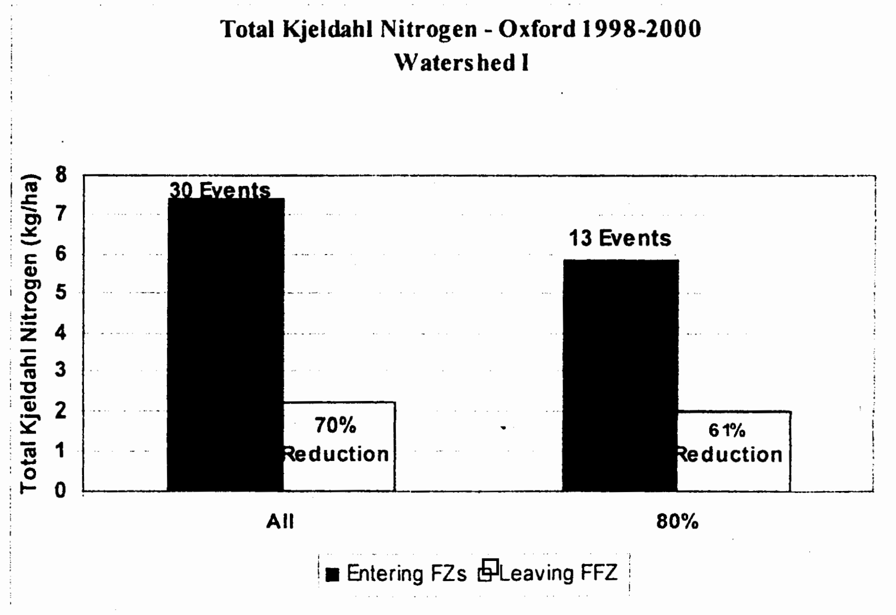
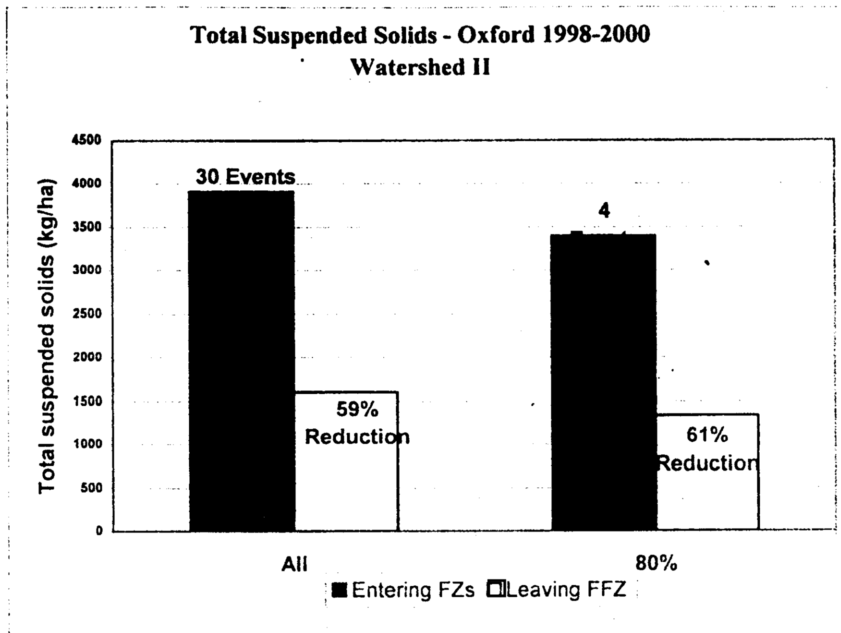
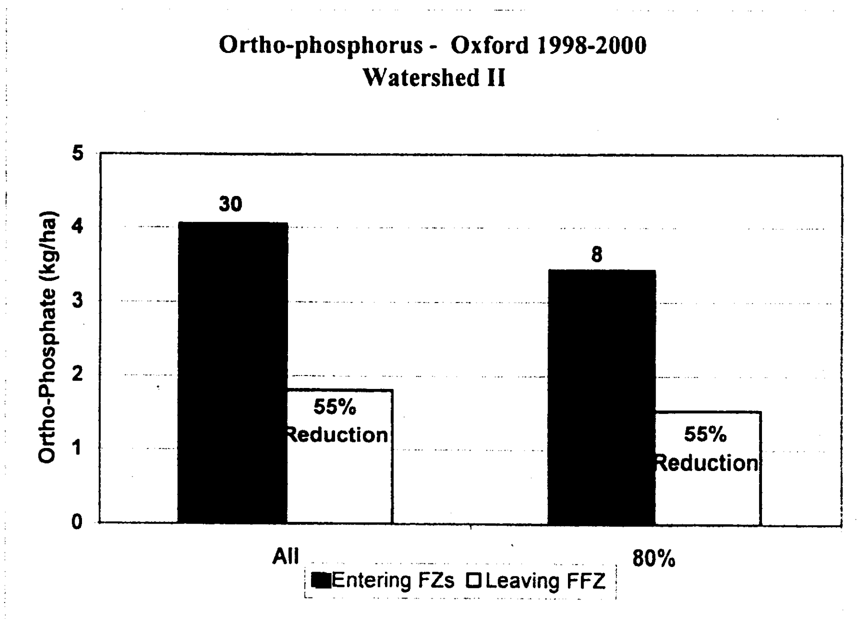


Figure 10. Gravimetric sum of total suspended solids, ortho-phosphorus, and total phosphorus entering the grassed and forested filter zones (FZs) and leaving the forested filter zones (FFZ) from December 16, 1998 to December 16, 2000 on Watershed II for all events and for the largest events contributing about 80 percent of the total for each analyte. Numbers over the "Entering FZs" bar are the number of runoff events. Numbers in front of the other bars are the percent of analytes detained by the FZs.





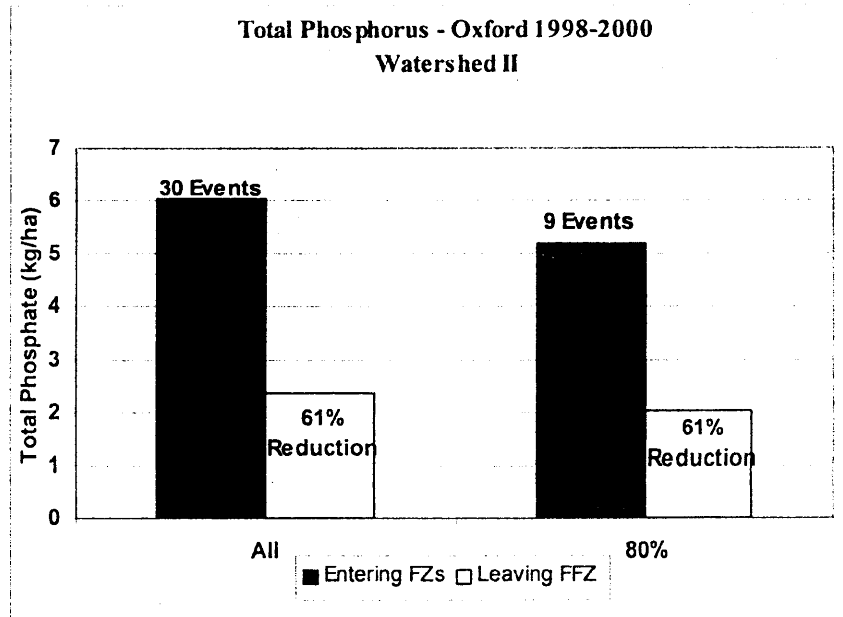
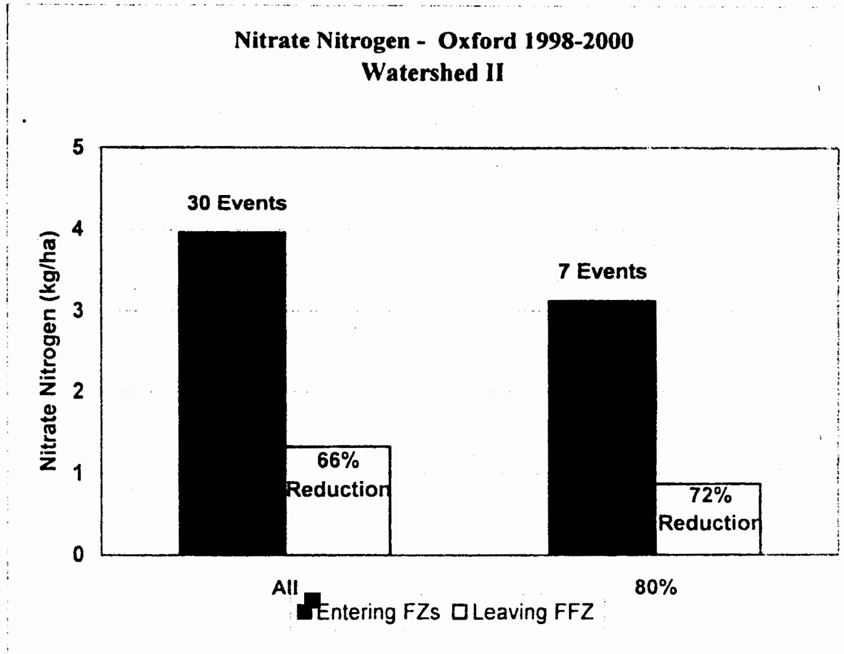
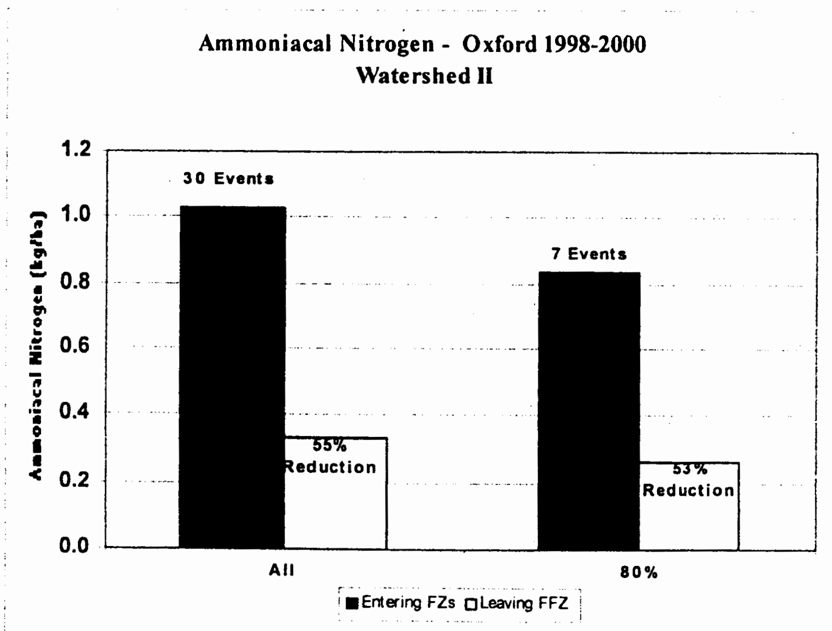
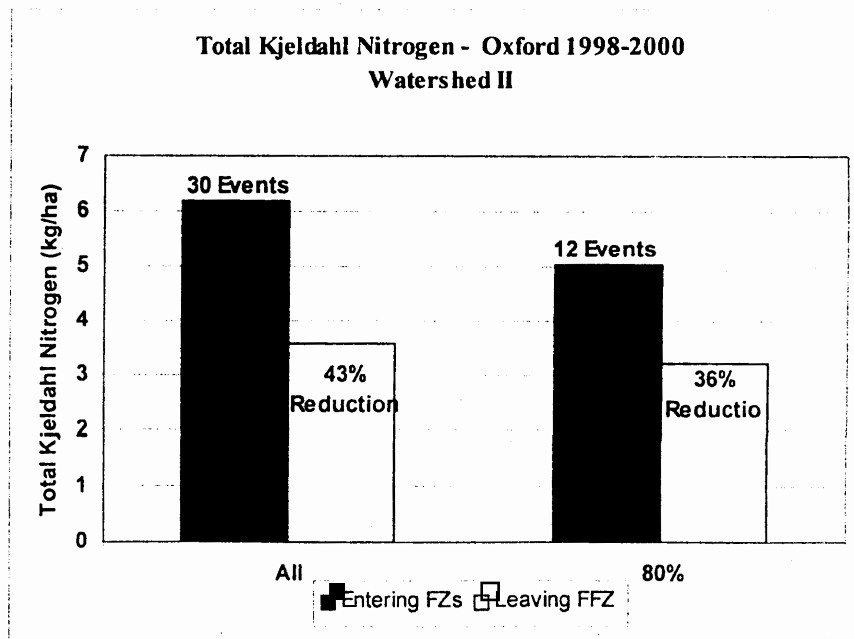


Figure 11. Gravimetric sum of nitrate nitrogen, ammoniacal nitrogen, and total Kjeldahl nitrogen entering the grassed and forested filter zones (FZs) and leaving the forested filter zones (FFZ) from December 16, 1998 to December 16, 2000 on Watershed II for all events and for the largest events contributing about 80 percent of the total for each analyte. Numbers over the "Entering FZs" bar are the number of runoff events. Numbers in front of the other bars are the percent of analytes detained by the FZs.







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APPENDIX 1

APPENDIX TABLES 1-9

Appendix Table 1. Cultivation practices and dates for crops grown during from fall 1998 through fall 2000 on two experimental watersheds

Date	Cultural practice	Conventional Tillage	No-Till
	---------------------------- Winter 1998-99 Cover Crop Cultivation ----------------------------		
9/15	Plowing	X	X
9/22	Fumigant injection (chloropicrin) @ 56.1 l/ha	X	X
10/22	Abruzi rye sown	X	X
	------------------------ 1999 Tobacco Crop Cultivation and Harvesting ---------------------		
4/16	Rye disked	X	
5/4	Rye sprayed with herbicide (Gramoxone) 3.5 l/ha		X
5/6	Rye sprayed with herbicide (Gramoxone) 3.5 l/ha		X
5/7	Fungicide application (Lorsban 15G) 7.02 l/ha	X	X
5/17	Beds formed and shaped	X	
5/19	Herbicide application (Command) 3.04 l/ha	X	X
5/20	Cultivation	X	
5/20	Fertilizer application (8-8-24) 560 kg/ha	X	X
6/8	Cultivation	X	
6/8	Fertilizer application (15-0-14) 168 kg/ha	X	X
6/12	Cultivation	X	
6/12	Fertilizer application (6-12-18) 187 kg/ha	X	X
6/27	Insecticide application (Orthene 75 SP) 1.12 kg/ha	X	X
6/28	Herbicide application (Devrinol 50W) 1.12 kg/ha	X	X
7/20	Sucker control (Offshoot-T) 18.7 l/ha	X	X
7/30	Sucker control (Offshoot-T) 18.7 l/ha	X	X
8/4	Insecticide application (Orthene 75 SP) 1.12 kg/ha	X	X
8/4-5	Harvesting	X	X
8/23	Sucker control (Prime+) 4.68 l/ha	X	X
8/30	Sucker control (Royal MH-30) 14.03 kg/ha	X	X
9/8-9	Harvesting	X	X
9/22-23	Harvesting	X	X

Appendix Table 1. (continued) Cultivation practices and dates for crops grown during from fall 1998 through fall 2000 on two experimental watersheds

Date	Cultural practice	Conventional Tillage	No-Till
	Winter 1999-2000 Cover Crop Cultivation		
10/29	Fields disked	X	X
10/29	Fumigant injection (chloropicrin) @ 56.1 l/ha	X	X
11/16	Abruzi rye sown	X	X
	2000 Tobacco Crop Cultivation and Harvesting		
4/21	Rye sprayed with herbicide (Gramoxone) 3.5 l/ha		X
4/24	Rye sprayed with herbicide (Gramoxone) 3.5 l/ha		X
4/24	Fungicide application (Ridomil) 1.17 l/ha		X
4/24	Fungicide application (Lorsban) 1.17 l/ha		X
5/8	Fungicide application (Ridomil) 1.17 l/ha	X	
5/8	Fungicide application (Lorsban) 1.17 l/ha	X	
5/9	Beds formed and shaped	X	
5/15	Herbicide application (Spartan) 0.39 l/ha	X	X
5/15	Herbicide application (Command) 3.04 l/ha	X	X
5/16	Tobacco planted	X	X
6/5	Cultivation	X	
6/5	Fertilizer application (8-8-24) 560 kg/ha	X	X
6/7	Herbicide application (Acrobat) 2.8 kg/ha	X	X
6/9	Cultivation	X	
6/9	Fertilizer application (15-0-14) 168 kg/ha	X	X
6/13	Insecticide application (Orthene 75 SP) 1.12 kg/ha	X	X
6/22	Herbicide application (Acrobat) 2.8 kg/ha	X	X
6/23	Insecticide application (Orthene 75 SP) 1.12 kg/ha	X	X
6/26	Cultivation	X	
6/26	Herbicide application (Devrinol 50W) 2.24 kg/ha	X	X
7/20	Sucker control (Offshoot-T) 18.7 l/ha	X	X
7/28	Sucker control (Offshoot-T) 18.7 l/ha	X	X
7/28	Insecticide application (Orthene 75 SP) 1.12 kg/ha	X	X
8/9	Insecticide application (Orthene 75 SP) 1.12 kg/ha	X	X
8/9	Sucker control (Prime+) 4.68 l/ha	X	X
8/14	Insecticide application (Orthene 75 SP) 1.12 kg/ha	X	X
8/19	Sucker control (Royal MH-30) 14.03 l/ha	X	X
8/10-11	Harvesting	X	X
9/5-6	Harvesting	X	X
9/19-20	Harvesting	X	X
10/31	Fields disked	X	X
11/1	Fescue cover crop sown	X	X

Appendix Table 2. Total rainfall, peak 5-minute rainfall, average 5-minute rainfall, total runoff, and peak runoff rates for events on Watershed I.

Julian Day	Year	Total Rainfall (mm)	Peak 5-Min. Rainfall (mm)	Average 5-min. Rainfall (mm)	Runoff No-Till Field (cu. M)	Runoff Conv. Tillage Field (cu. M)	Runoff GFZ-I (cu. M)	Runoff FFZ-I (cu. M)	Peak Runoff No-Till Field (CMH)	Peak Runoff Conv. Tillage Field (CMH)	Peak Runoff GFZ-I (CMH)	Peak Runoff FFZ-I (CMH)
350	1998	15.8	-	-	15.223	8.788	12.47	15.19	7.67	5.46	7.571	8.317
17	1999	11.9	2.9	0.28	21.346	17.082	23.43	11.02	28.34	13.325	20.71	2.57
23	1999	53.1	2.1	0.27	134.16	166.075	242.24	190.49	25.181	28.34	44.04	40.86
32	1999	17.3	0.5	0.16	17.472	12.61	16.81	12.7	6.162	6.162	8.2	2.94
73	1999	38.2	2.8	0.28	76.336	86.736	128.71	89.87	37.31	37.31	56.38	33.91
80	1999	27.3	2.2	0.51	68.484	75.985	122.17	100.55	82.251	82.251	131.75	129.05
91	1999	28.5	1.4	0.45	57.473	58.539	87.23	60.91	35.464	35.464	51.49	32.83
101	1999	17.5	2.1	0.49	24.622	19.11	30.51	15.1	39.286	31.772	38.32	14.69
118	1999	48.9	0.8	0.18	39.013	27.781	44.97	34.5	16.809	8.502	20.45	14.52
237	1999	29.9	7.6	1.5	69.628	105.573	206.51	32.89	196.417	228.046	499.9	72.65
247	1999	107.2	1.9	0.37	189.163	275.288	503.79	274.66	43.498	54.834	97.17	42.18
258	1999	123.5	1.6	0.41	495.105	623.506	1275.79	592.97	85.423	105.456	216.94	64.44
148	2000	11.68	2.54	0.83	91.61	12.40	19.29	0.08	54.83	23.60	21.64	0.14
167	2000	21.60	3.60	0.40	35.40	1.31	0.00	0.00	50.09	1.03	0.00	0.00
171	2000	16.26	6.10	1.16	33.22	127.97	45.19	0.85	105.46	59.85	71.43	1.70
205	2000	33.53	0.76	0.36	75.88	42.55	98.07	2.67	18.07	14.43	30.04	0.70
214	2000	11.18	1.78	0.47	26.96	15.96	36.61	0.30	28.34	20.70	34.14	0.55
216	2000	33.53	4.06	1.68	123.55	122.51	275.19	107.91	116.40	112.71	243.77	88.11
217	2000	17.53	9.91	2.92	80.20	77.86	179.95	77.56	185.87	136.18	272.28	128.00
223	2000	30.23	11.18	1.44	92.90	95.93	202.95	77.25	185.87	153.31	297.44	130.91

Appendix Table 2. (continued) Total rainfall, peak 5-minute rainfall, average 5-minute rainfall, total runoff, and peak runoff rates for events on Watershed I.

Julian Day	Year	Total Rainfall (mm)	Peak 5-Min. Rainfall (mm)	Average 5-min. Rainfall (mm)	Runoff No-Till Field (cu. M)	Runoff Conv. Tillage Field (cu. M)	Runoff GFZ-I (cu. M)	Runoff FFZ-I (cu. M)	Peak Runoff No-Till Field (CMH)	Peak Runoff Conv. Tillage Field (CMH)	Peak Runoff GFZ-I (CMH)	Peak Runoff FFZ-I (CMH)
226	2000	8.89	3.81	1.48	23.70	17.45	30.73	1.71	31.77	30.06	40.39	1.33
243	2000	11.18	1.27	0.43	22.37	14.03	26.42	2.14	20.70	20.70	29.65	0.77
244a	2000	5.08	1.52	0.64	15.60	10.06	21.66	4.64	16.81	16.81	23.51	2.37
244b	2000	4.57	2.29	1.14	10.15	6.42	12.42	1.27	13.33	12.27	11.38	0.29
246	2000	13.21	3.05	0.94	38.65	36.89	74.67	22.83	33.62	45.60	86.37	23.02
247	2000	2.90	1.90	0.48	7.85	4.02	0.00	0.00	6.89	6.16	0.00	0.00
248	2000	17.27	4.06	0.60	59.85	48.35	119.81	45.95	79.22	67.76	129.83	51.49
268	2000	11.18	2.29	1.02	30.91	25.75	120.19	6.17	33.62	39.29	169.32	4.89
269	2000	21.84	4.06	0.50	77.10	69.47	159.57	61.32	88.58	88.58	165.35	67.59
351	2000	33.90	4.80	0.85	154.28	151.37	319.01	104.16	295.28	263.64	703.82	288.23

Appendix Table 3. Total rainfall, peak 5-minute rainfall, average 5-minute rainfall, total runoff, and peak runoff rates for events on Watershed II.

Julian Day	Year	Total Rainfall (mm)	Peak 5-Min. Rainfall (mm)	Average 5-min. Rainfall (mm)	Runoff No-Till Field (cu. M)	Runoff Conv. Tillage Field (cu. M)	Runoff GFZ-II (cu. M)	Runoff FFZ-II (cu. M)	Peak Runoff No-Till Field (CMH)	Peak Runoff Conv. Tillage Field (CMH)	Peak Runoff GFZ-II (CMH)	Peak Runoff FFZ-II (CMH)
350	1998	15.80	-	-	11.41	1.83	27.32	0.22	6.16	2.64	12.56	0.41
17	1999	11.90	2.90	0.28	24.69	4.94	44.18	3.81	28.34	6.16	33.34	2.92
23	1999	53.10	2.10	0.27	170.08	67.80	360.35	342.21	26.75	13.33	53.27	52.10
32	1999	17.30	0.50	0.16	21.15	2.48	39.66	8.53	6.89	1.73	12.82	3.39
73	1999	38.20	2.80	0.28	84.24	35.41	170.43	104.46	31.77	18.07	60.27	37.66
80	1999	27.30	2.20	0.51	73.96	35.66	151.76	86.32	70.53	41.39	133.51	73.73
91	1999	28.50	1.40	0.45	57.93	25.69	117.79	66.83	33.62	18.07	60.43	27.45
101	1999	17.50	2.10	0.49	22.28	7.36	38.57	2.23	37.31	15.60	56.60	3.82
118	1999	48.90	0.80	0.18	28.87	6.27	71.32	20.82	13.33	3.12	26.20	12.99
237	1999	29.90	7.60	1.50	84.29	51.95	217.57	41.84	201.68	212.24	461.45	90.30
247	1999	107.20	1.90	0.37	200.30	69.32	494.10	467.10	43.50	28.34	115.40	65.80
258	1999	123.50	1.60	0.41	523.12	306.62	1120.89	1318.54	85.42	62.35	209.02	215.52
148	2000	11.68	2.54	0.83	14.31	11.00	26.63	2.19	23.60	31.77	31.47	3.80
167	2000	21.60	3.60	0.40	25.35	1.46	22.68	0.13	37.31	4.20	31.72	0.34
171	2000	16.26	6.10	1.16	27.07	24.67	56.77	13.97	64.99	124.18	131.87	19.41
205	2000	33.53	0.76	0.36	53.03	17.23	66.98	21.23	15.60	8.50	30.78	14.47
214	2000	11.18	1.78	0.47	20.61	9.89	0.00	0.00	23.60	25.18	0.00	0.00
216	2000	33.53	4.06	1.68	116.44	83.01	270.26	211.43	120.22	132.08	263.46	159.48
217	2000	17.53	9.91	2.92	74.11	54.29	164.69	149.01	153.31	212.24	299.26	215.59
223	2000	30.23	11.18	1.44	86.96	75.32	192.77	137.83	157.79	212.24	295.98	201.71

Appendix Table 3. (continued) Total rainfall, peak 5-minute rainfall, average 5-minute rainfall, total runoff, and peak runoff rates for events on Watershed II.

Julian Day	Year	Total Rainfall (mm)	Peak 5-Min. Rainfall (mm)	Average 5-min. Rainfall (mm)	Runoff No-Till Field (cu. M)	Runoff Conv. Tillage Field (cu. M)	Runoff GFZ-II (cu. M)	Runoff FFZ-II (cu. M)	Peak Runoff No-Till Field (CMH)	Peak Runoff Conv. Tillage Field (CMH)	Peak Runoff GFZ-II (CMH)	Peak Runoff FFZ-II (CMH)
226	2000	8.89	3.81	1.48	18.51	14.18	35.14	13.90	26.75	31.77	43.44	16.14
243	2000	11.18	1.27	0.43	13.40	9.09	23.76	11.61	16.81	20.70	25.55	12.64
244a	2000	5.08	1.52	0.64	10.58	5.46	0.00	0.00	14.43	18.07	0.00	0.00
244b	2000	4.57	2.29	1.14	5.16	3.41	0.00	0.00	6.89	12.27	0.00	0.00
246	2000	13.21	3.05	0.94	32.47	23.04	70.11	47.90	33.62	37.31	68.33	46.26
247	2000	2.90	1.90	0.48	4.00	1.83	6.84	3.11	4.81	6.89	5.97	3.04
248	2000	17.27	4.06	0.60	43.98	21.75	79.41	70.57	50.09	43.50	87.37	72.82
268	2000	11.18	2.29	1.02	23.57	15.77	45.94	23.77	30.06	33.62	51.81	24.82
269	2000	21.84	4.06	0.50	68.30	39.99	142.74	123.67	79.22	91.88	173.66	114.45
351	2000	33.90	4.80	0.85	132.98	97.33	273.02	158.47	263.64	282.10	459.39	251.97

Appendix Table 4. Total suspended solids in runoff from fields, grassed filter zones and forested filter zones.

Julian Day	Year	Total TSS in Runoff No-Till Field WS-I (kg)	Total TSS in Runoff Conv. Field WS-I (kg)	Total TSS in Runoff GFZ-I (kg)	Total TSS in Runoff FFZ-I (kg)	Total TSS in Runoff No-Till Field WS-II (kg)	Total TSS in Runoff Conv. Field WS-II (kg)	Total TSS in Runoff GFZ-II (kg)	Total TSS in Runoff FFZ-II (kg)
350	1998	3.74	0.51	2.07	1.76	0.79	0.98	2.51	0.00
17	1999	28.35	11.92	27.84	0.00	12.35	4.21	6.63	1.19
23	1999	38.91	13.95	30.04	16.00	14.96	8.94	35.31	27.38
32	1999	3.19	0.00	0.74	0.00	1.27	0.00	0.63	0.00
73	1999	30.54	11.45	12.10	6.65	2.03	9.00	15.00	12.12
80	1999	27.26	10.34	23.21	11.87	6.96	7.28	13.96	9.50
91	1999	12.53	3.86	6.80	0.67	3.07	2.74	3.30	4.68
101	1999	6.33	2.07	3.45	1.49	1.03	0.82	1.81	0.30
118	1999	4.60	0.00	3.87	1.10	0.47	0.00	2.00	1.42
237	1999	17.97	147.38	169.75	18.02	11.54	131.94	355.94	38.41
247	1999	6.44	33.31	27.20	6.87	1.81	20.66	35.08	32.23
258	1999	36.63	94.77	59.96	26.68	14.12	99.35	84.07	97.57
148	2000	14.76	8.09	3.26	0.00	0.18	0.68	1.07	0.43
167	2000	0.11	0.00	0.00	0.00	0.66	0.45	2.38	0.00
171	2000	10.10	188.12	18.89	0.00	3.25	64.05	103.78	5.64
205	2000	3.57	7.19	11.28	0.00	1.64	18.95	9.58	3.67
214	2000	2.96	7.94	7.40	0.00	1.01	2.80	0.00	0.00
216	2000	13.96	25.36	114.20	21.37	8.62	68.40	144.05	129.18
217	2000	19.41	42.82	99.33	19.78	12.97	138.11	204.05	99.69
223	2000	29.45	99.00	120.76	32.14	28.00	143.41	165.01	98.96
226	2000	7.28	16.09	18.99	0.00	7.72	32.28	32.75	6.17
243	2000	0.96	0.72	2.03	0.00	0.60	1.36	6.08	1.53
244a	2000	0.52	0.40	1.26	0.00	0.31	2.21	0.00	0.00
244b	2000	0.59	0.39	0.94	0.00	0.27	2.13	0.00	0.00
246	2000	3.01	9.04	5.60	1.71	0.42	9.40	14.37	10.83
247	2000	0.66	0.42	0.00	0.00	0.18	1.16	2.41	0.00
248	2000	6.10	5.56	13.18	4.32	2.07	9.44	16.44	11.15
268	2000	0.96	2.37	5.89	0.00	1.81	2.81	4.55	2.76
269	2000	0.82	0.10	18.03	4.42	0.17	10.60	22.41	13.36
351	2000	473.33	980.88	1632.69	1049.10	698.92	648.78	3059.99	1596.14

Appendix Table 5. Total ammoniacal nitrogen loading in runoff from fields, grassed filter zones and forested filter zones.

Julian Day	Year	Total NH_4-N in Runoff No-Till Field WS-I (kg)	Total NH_4-N in Runoff Conv. Field WS-I (kg)	Total NH_4-N in Runoff GFZ-I (kg)	Total NH_4-N in Runoff FFZ-I (kg)	Total NH_4-N in Runoff No-Till Field WS-II (kg)	Total NH_4-N in Runoff Conv. Field WS-II (kg)	Total NH_4-N in Runoff GFZ-II (kg)	Total NH_4-N in Runoff FFZ-II (kg)
350	1998	0.003	0.001	0.001	0.002	0.001	0.000	0.003	0.000
17	1999	0.004	0.001	0.002	0.000	0.003	0.000	0.004	0.000
23	1999	0.013	0.017	0.024	0.019	0.017	0.007	0.036	0.034
32	1999	0.001	0.000	0.002	0.000	0.003	0.000	0.004	0.000
73	1999	0.016	0.009	0.021	0.009	0.047	0.004	0.022	0.010
80	1999	0.012	0.014	0.018	0.011	0.017	0.004	0.030	0.017
91	1999	0.005	0.027	0.009	0.006	0.008	0.018	0.012	0.007
101	1999	0.009	0.005	0.012	0.002	0.012	0.001	0.010	0.000
118	1999	0.007	0.000	0.005	0.003	0.004	0.000	0.007	0.002
237	1999	0.007	0.010	0.330	0.011	0.008	0.005	0.033	0.007
247	1999	0.020	0.027	0.050	0.154	0.020	0.007	0.049	0.047
258	1999	0.049	0.062	0.128	0.059	0.052	0.031	0.112	0.132
148	2000	0.009	0.001	0.002	0.000	0.001	0.003	0.003	0.000
167	2000	0.033	0.000	0.000	0.000	0.018	0.001	0.002	0.000
171	2000	0.004	0.013	0.005	0.000	0.003	0.003	0.006	0.001
205	2000	0.008	0.004	0.010	0.000	0.005	0.001	0.007	0.002
214	2000	0.003	0.001	0.004	0.000	0.003	0.001	0.000	0.000
216	2000	0.013	0.012	0.028	0.011	0.012	0.008	0.027	0.021
217	2000	0.009	0.008	0.018	0.008	0.008	0.005	0.016	0.015
223	2000	0.009	0.009	0.020	0.008	0.009	0.035	0.019	0.014
226	2000	0.005	0.014	0.003	0.000	0.001	0.014	0.004	0.001
243	2000	0.012	0.003	0.005	0.000	0.004	0.004	0.006	0.004
244a	2000	0.005	0.001	0.005	0.000	0.003	0.001	0.000	0.000
244b	2000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.000
246	2000	0.004	0.004	0.007	0.002	0.003	0.003	0.007	0.005
247	2000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000
248	2000	0.007	0.005	0.012	0.005	0.004	0.003	0.014	0.008
268	2000	0.007	0.004	0.026	0.000	0.013	0.003	0.007	0.002
269	2000	0.008	0.008	0.027	0.009	0.007	0.004	0.014	0.012
351	2000	0.293	0.394	0.166	0.047	0.293	0.282	0.382	0.122

Appendix Table 6. Total nitrate nitrogen loading in runoff from fields, grassed filter zones and forested filter zones.

Julian Day	Year	Total NO3-N in Runoff No-Till Field WS-I (kg)	Total NO3-N in Runoff Conv. Field WS-I (kg)	Total NO3-N in Runoff GFZ-I (kg)	Total NO3-N in Runoff FFZ-I (kg)	Total NO3-N in Runoff No-Till Field WS-II (kg)	Total NO3-N in Runoff Conv. Field WS-II (kg)	Total NO3-N in Runoff GFZ-II (kg)	Total NO3-N in Runoff FFZ-II (kg)
350	1998	0.001	0.001	0.003	0.002	0.003	0.000	0.012	0.000
17	1999	0.003	0.001	0.012	0.000	0.004	0.000	0.009	0.001
23	1999	0.013	0.017	0.024	0.023	0.017	0.007	0.036	0.034
32	1999	0.001	0.000	0.002	0.000	0.003	0.000	0.004	0.000
73	1999	0.008	0.009	0.014	0.030	0.008	0.004	0.017	0.017
80	1999	0.007	0.008	0.012	0.017	0.008	0.004	0.015	0.009
91	1999	0.017	0.020	0.016	0.017	0.043	0.049	0.033	0.016
101	1999	0.003	0.001	0.003	0.006	0.003	0.001	0.004	0.001
118	1999	0.004	0.000	0.004	0.004	0.003	0.000	0.007	0.002
237	1999	0.077	0.116	1.053	0.118	0.109	0.068	0.740	0.130
247	1999	0.020	0.036	0.232	0.797	0.020	0.010	0.326	0.149
258	1999	0.049	0.138	0.255	0.178	0.057	0.068	0.235	0.264
148	2000	0.101	0.009	0.013	0.000	0.009	0.003	0.013	0.001
167	2000	0.602	0.000	0.000	0.000	0.558	0.016	0.386	0.000
171	2000	0.166	0.563	0.217	0.000	0.205	0.135	0.471	0.071
205	2000	0.047	0.023	0.082	0.000	0.039	0.017	0.064	0.017
214	2000	0.027	0.010	0.022	0.000	0.029	0.007	0.000	0.000
216	2000	0.120	0.062	0.242	0.129	0.129	0.036	0.378	0.211
217	2000	0.088	0.057	0.180	0.055	0.104	0.049	0.231	0.149
223	2000	0.195	0.144	0.304	0.116	0.200	0.040	0.366	0.248
226	2000	0.023	0.001	0.049	0.000	0.039	0.003	0.039	0.015
243	2000	0.005	0.001	0.013	0.000	0.004	0.001	0.007	0.003
244a	2000	0.001	0.001	0.003	0.000	0.001	0.001	0.000	0.000
244b	2000	0.004	0.003	0.006	0.000	0.001	0.001	0.000	0.000
246	2000	0.029	0.022	0.075	0.020	0.021	0.018	0.048	0.041
247	2000	0.003	0.001	0.000	0.000	0.001	0.001	0.004	0.000
248	2000	0.020	0.012	0.053	0.023	0.009	0.010	0.015	0.017
268	2000	0.022	0.012	0.078	0.000	0.010	0.009	0.022	0.014
269	2000	0.014	0.014	0.045	0.019	0.014	0.023	0.030	0.027
351	2000	0.494	0.303	1.085	0.240	0.412	0.254	0.901	0.396

Appendix Table 7. Total Kjeldehl nitrogen loading in runoff from fields, grassed filter zones and forested filter zones.

Julian Day	Year	Total TKN in Runoff No-Till Field WS-I (kg)	Total TKN in Runoff Conv. Field WS-I (kg)	Total TKN in Runoff GFZ-I (kg)	Total TKN in Runoff FFZ-I (kg)	Total TKN in Runoff No-Till Field WS-II (kg)	Total TKN in Runoff Conv. Field WS-II (kg)	Total TKN in Runoff GFZ-II (kg)	Total TKN in Runoff FFZ-II (kg)
350	1998	0.010	0.008	0.010	0.015	0.009	0.003	0.022	0.000
17	1999	0.044	0.029	0.066	0.000	0.035	0.007	0.066	0.007
23	1999	0.126	0.183	0.291	0.190	0.204	0.088	0.432	0.342
32	1999	0.021	0.000	0.016	0.000	0.023	0.000	0.048	0.000
73	1999	0.107	0.072	0.154	0.084	0.160	0.033	0.148	0.103
80	1999	0.069	0.069	0.147	0.096	0.072	0.031	0.150	0.138
91	1999	0.047	0.065	0.045	0.041	0.038	0.039	0.069	0.057
101	1999	0.036	0.021	0.037	0.013	0.031	0.008	0.030	0.002
118	1999	0.033	0.000	0.045	0.029	0.021	0.000	0.051	0.020
237	1999	0.077	0.169	0.661	0.021	0.069	0.046	0.413	0.054
247	1999	0.142	0.182	0.348	0.467	0.134	0.020	0.341	0.453
258	1999	0.545	0.449	1.225	0.652	0.517	0.199	1.233	1.582
148	2000	0.156	0.022	0.056	0.000	0.001	0.021	0.040	0.006
167	2000	0.156	0.000	0.000	0.000	0.096	0.004	0.054	0.000
171	2000	0.064	0.192	0.072	0.000	0.046	0.055	0.097	0.032
205	2000	0.107	0.064	0.147	0.000	0.085	0.017	0.094	0.034
214	2000	0.060	0.022	0.073	0.000	0.046	0.013	0.000	0.000
216	2000	0.148	0.095	0.413	0.248	0.174	0.061	0.351	0.317
217	2000	0.144	0.078	0.270	0.109	0.134	0.075	0.214	0.209
223	2000	0.251	0.230	0.609	0.193	0.235	0.264	0.617	0.358
226	2000	0.092	0.075	0.086	0.000	0.078	0.053	0.081	0.026
243	2000	0.077	0.030	0.079	0.000	0.043	0.020	0.074	0.029
244a	2000	0.046	0.020	0.052	0.000	0.031	0.010	0.000	0.000
244b	2000	0.026	0.013	0.035	0.000	0.014	0.009	0.000	0.000
246	2000	0.100	0.034	0.194	0.057	0.100	0.053	0.196	0.115
247	2000	0.023	0.008	0.000	0.000	0.010	0.005	0.017	0.000
248	2000	0.144	0.092	0.264	0.106	0.114	0.042	0.214	0.191
268	2000	0.092	0.062	0.228	0.000	0.073	0.030	0.096	0.081
269	2000	0.139	0.139	0.319	0.129	0.151	0.072	0.300	0.284
351	2000	1.002	1.014	1.276	0.406	0.957	0.564	1.447	0.460

Appendix Table 8. Total ortho-phosphorus loading in runoff from fields, grassed filter zones and forested filter zones.

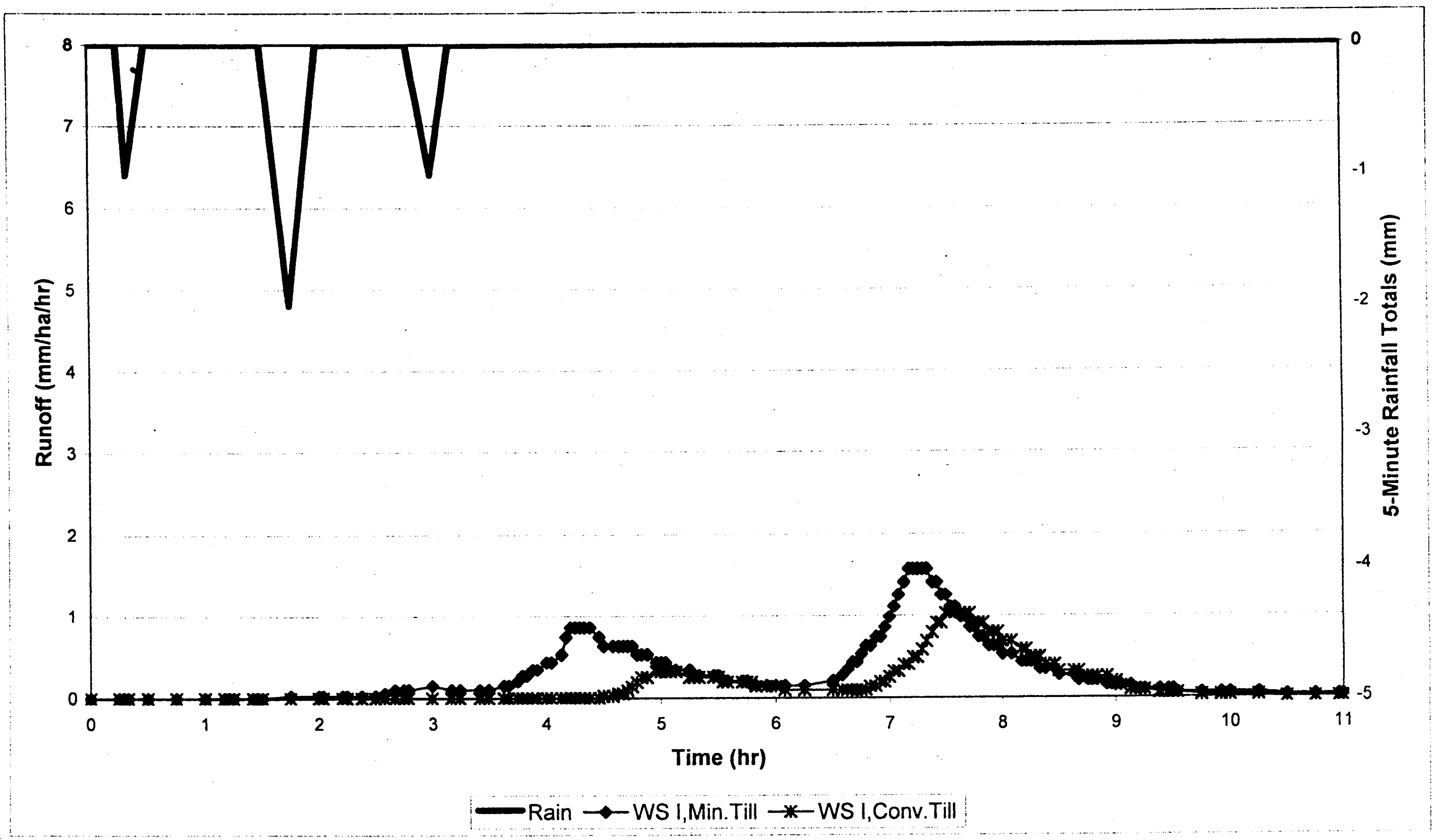
Julian Day	Year	Total OP in Runoff No-Till Field WS-I (kg)	Total OP in Runoff Conv. Field WS-I (kg)	Total OP in Runoff GFZ-I (kg)	Total OP in Runoff FFZ-I (kg)	Total OP in Runoff No-Till Field WS-II (kg)	Total OP in Runoff Conv. Field WS-II (kg)	Total OP in Runoff GFZ-II (kg)	Total OP in Runoff FFZ-II (kg)
350	1998	0.005	0.008	0.009	0.009	0.008	0.001	0.016	0.000
17	1999	0.008	0.017	0.023	0.000	0.016	0.001	0.018	0.002
23	1999	0.060	0.116	0.162	0.093	0.111	0.035	0.180	0.123
32	1999	0.009	0.000	0.010	0.000	0.008	0.000	0.012	0.000
73	1999	0.023	0.033	0.048	0.026	0.013	0.008	0.034	0.021
80	1999	0.022	0.030	0.045	0.032	0.020	0.009	0.035	0.020
91	1999	0.020	0.035	0.038	0.020	0.022	0.017	0.029	0.017
101	1999	0.014	0.012	0.020	0.006	0.008	0.003	0.012	0.001
118	1999	0.010	0.000	0.021	0.010	0.007	0.000	0.019	0.005
237	1999	0.125	0.126	0.330	0.049	0.160	0.057	0.370	0.059
247	1999	0.208	0.254	0.504	0.159	0.260	0.055	0.544	0.308
258	1999	0.545	0.593	1.148	0.374	0.628	0.248	1.121	0.765
148	2000	0.183	0.017	0.029	0.000	0.018	0.007	0.029	0.002
167	2000	0.113	0.000	0.000	0.000	0.099	0.003	0.070	0.000
171	2000	0.047	0.320	0.095	0.000	0.048	0.027	0.044	0.022
205	2000	0.057	0.029	0.108	0.000	0.049	0.009	0.054	0.013
214	2000	0.033	0.013	0.044	0.000	0.022	0.005	0.000	0.000
216	2000	0.087	0.056	0.259	0.098	0.086	0.044	0.170	0.112
217	2000	0.035	0.031	0.155	0.052	0.052	0.018	0.066	0.066
223	2000	0.091	0.056	0.264	0.076	0.086	0.060	0.147	0.108
226	2000	0.031	0.013	0.031	0.000	0.021	0.004	0.020	0.008
243	2000	0.025	0.009	0.026	0.000	0.013	0.004	0.015	0.006
244a	2000	0.014	0.005	0.017	0.000	0.010	0.001	0.000	0.000
244b	2000	0.012	0.005	0.011	0.000	0.005	0.001	0.000	0.000
246	2000	0.043	0.023	0.075	0.015	0.042	0.012	0.065	0.036
247	2000	0.007	0.003	0.000	0.000	0.005	0.001	0.003	0.000
248	2000	0.053	0.031	0.108	0.030	0.048	0.009	0.062	0.047
268	2000	0.052	0.023	0.156	0.000	0.029	0.012	0.040	0.021
269	2000	0.051	0.066	0.150	0.042	0.068	0.029	0.108	0.088
351	2000	0.818	0.742	1.563	0.469	0.638	0.458	1.229	0.634

Appendix Table 9. Total phosphorus loading in runoff from fields, grassed filter zones and forested filter zones.

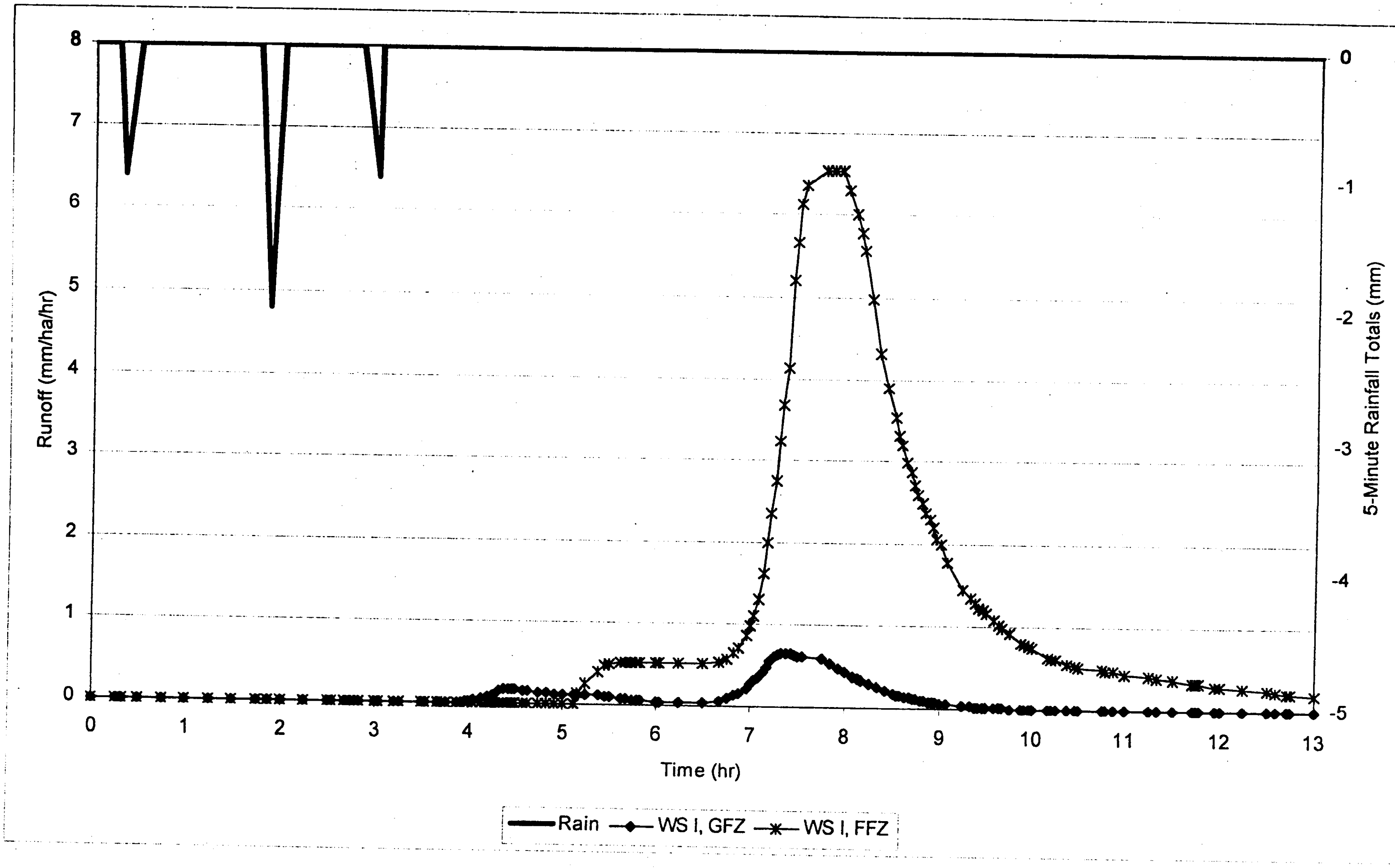
Julian Day	Year	Total TP in Runoff No-Till Field WS-I (kg)	Total TP in Runoff Conv. Field WS-I (kg)	Total TP in Runoff GFZ-I (kg)	Total TP in Runoff FFZ-I (kg)	Total TP in Runoff No-Till Field WS-II (kg)	Total TP in Runoff Conv. Field WS-II (kg)	Total TP in Runoff GFZ-II (kg)	Total TP in Runoff FFZ-II (kg)
350	1998	0.010	0.009	0.011	0.010	0.009	0.001	0.021	0.000
17	1999	0.030	0.026	0.047	0.000	0.027	0.005	0.040	0.003
23	1999	0.117	0.155	0.242	0.120	0.131	0.062	0.234	0.168
32	1999	0.012	0.000	0.012	0.000	0.009	0.000	0.013	0.000
73	1999	0.052	0.051	0.073	0.040	0.022	0.017	0.056	0.029
80	1999	0.042	0.048	0.078	0.048	0.034	0.014	0.062	0.033
91	1999	0.035	0.042	0.048	0.024	0.025	0.020	0.041	0.023
101	1999	0.022	0.016	0.026	0.009	0.010	0.004	0.015	0.001
118	1999	0.017	0.000	0.027	0.012	0.008	0.000	0.025	0.007
237	1999	0.133	0.190	0.372	0.056	0.177	0.073	0.479	0.071
247	1999	0.283	0.413	0.655	0.467	0.341	0.066	0.791	0.416
258	1999	0.644	1.746	1.531	0.504	0.680	0.276	1.793	0.923
148	2000	0.220	0.027	0.035	0.000	0.029	0.010	0.043	0.002
167	2000	0.138	0.000	0.000	0.000	0.134	0.004	0.093	0.000
171	2000	0.060	0.397	0.117	0.000	0.073	0.039	0.074	0.028
205	2000	0.107	0.047	0.137	0.000	0.079	0.017	0.087	0.021
214	2000	0.046	0.023	0.055	0.000	0.035	0.009	0.000	0.000
216	2000	0.161	0.116	0.385	0.140	0.129	0.073	0.324	0.205
217	2000	0.070	0.068	0.216	0.064	0.082	0.043	0.165	0.124
223	2000	0.121	0.091	0.345	0.108	0.113	0.159	0.289	0.165
226	2000	0.043	0.021	0.037	0.000	0.036	0.020	0.039	0.013
243	2000	0.036	0.014	0.040	0.000	0.020	0.010	0.029	0.010
244a	2000	0.022	0.012	0.026	0.000	0.020	0.005	0.000	0.000
244b	2000	0.016	0.008	0.015	0.000	0.008	0.004	0.000	0.000
246	2000	0.055	0.044	0.105	0.030	0.065	0.036	0.084	0.048
247	2000	0.010	0.004	0.000	0.000	0.008	0.003	0.006	0.000
248	2000	0.078	0.053	0.144	0.046	0.079	0.023	0.095	0.078
268	2000	0.068	0.036	0.192	0.000	0.044	0.016	0.055	0.031
269	2000	0.092	0.098	0.207	0.057	0.103	0.038	0.143	0.136
351	2000	0.972	0.832	1.882	0.521	0.745	0.555	1.638	0.729

APPENDIX 2

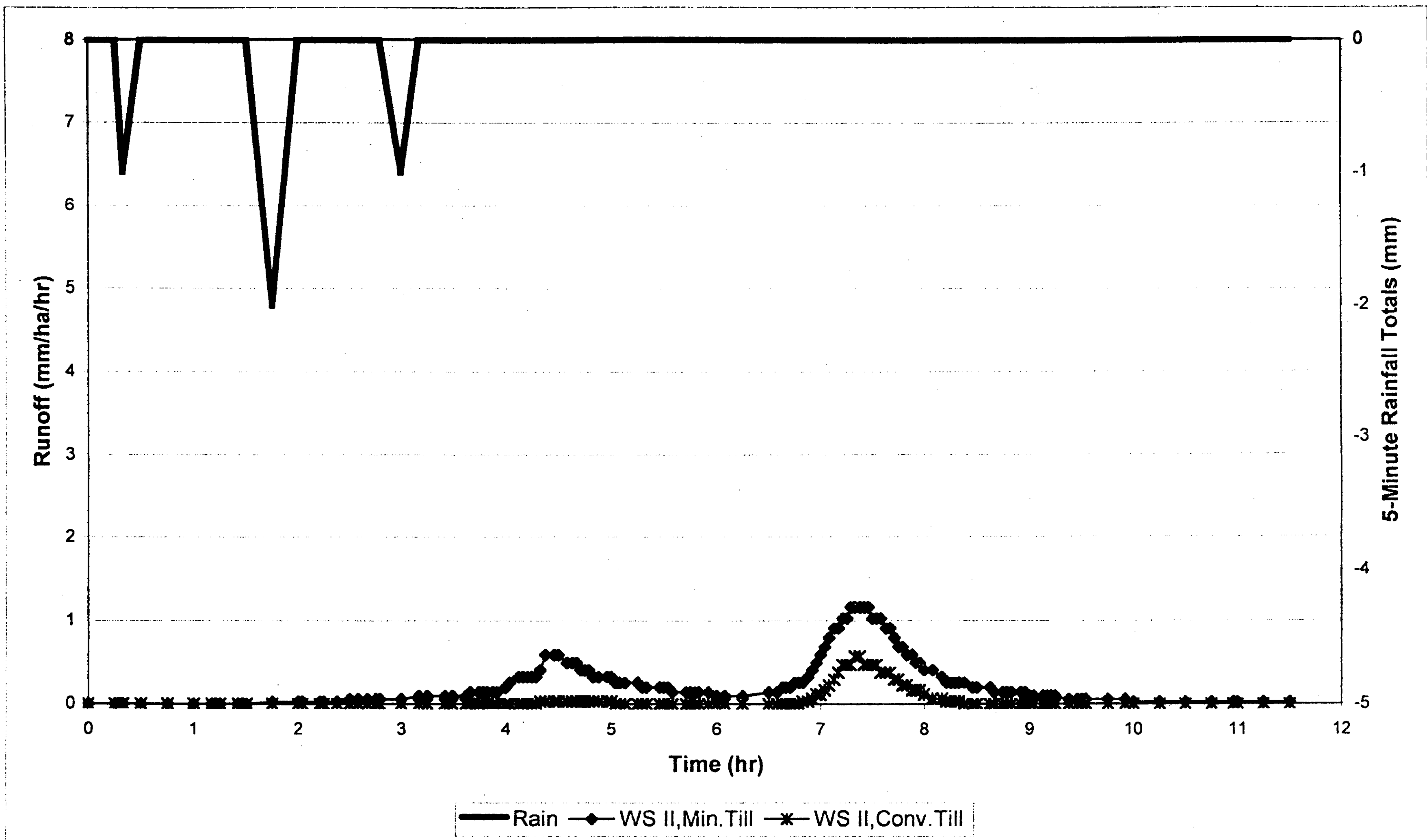
RAINFALL EVENT HYDROGRAPHS FOR 1998-99



Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 359, 1998.



Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 359, 1998.



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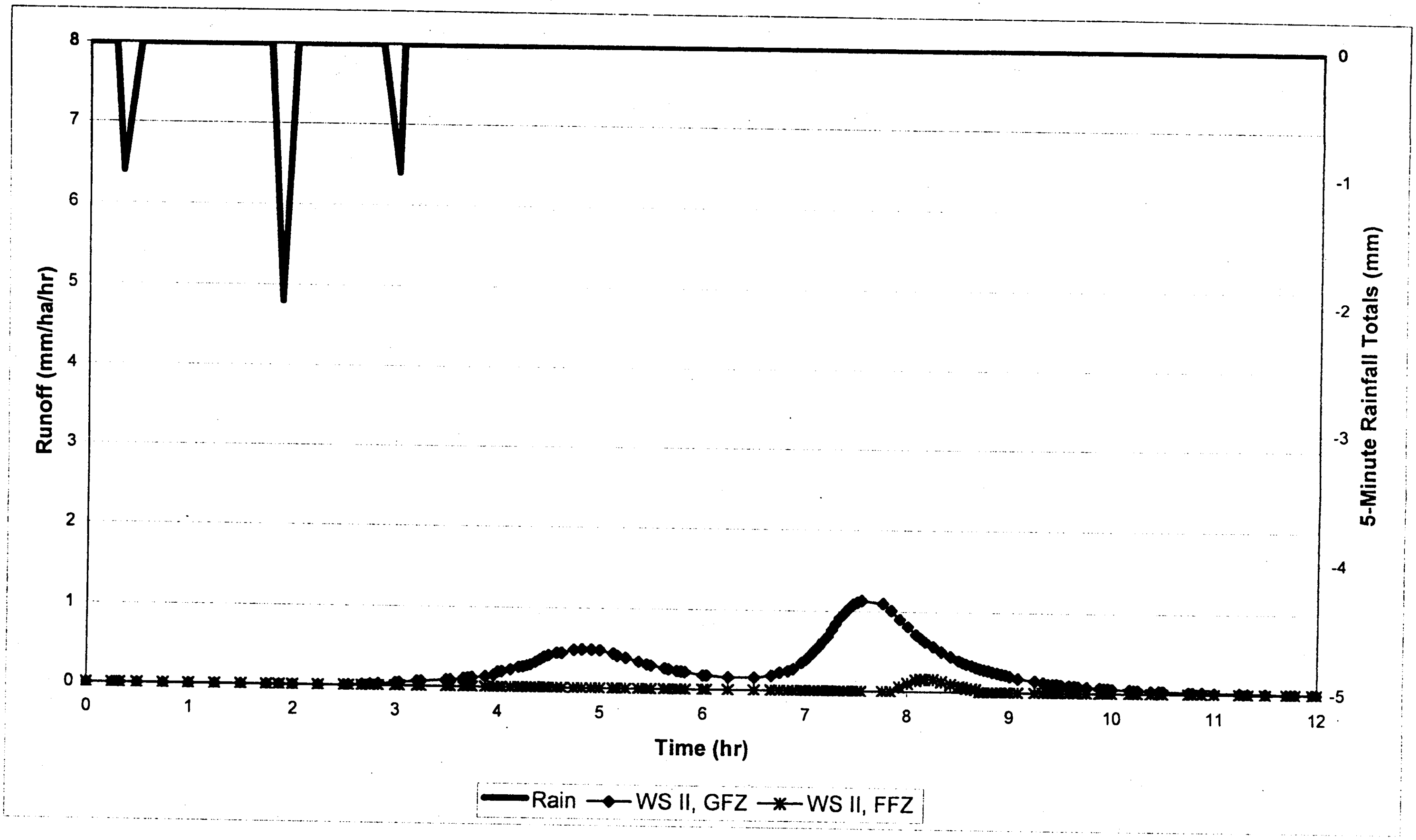

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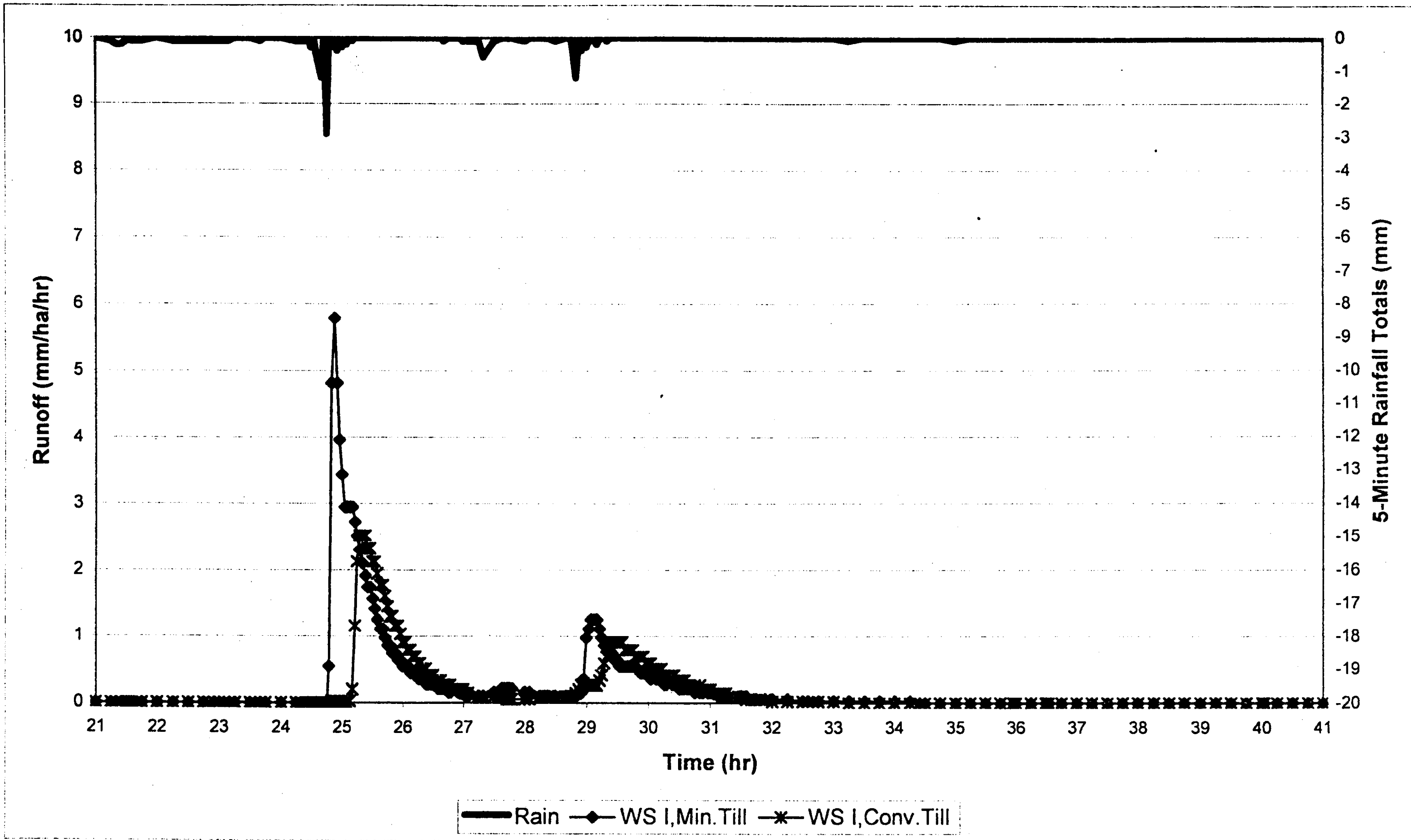

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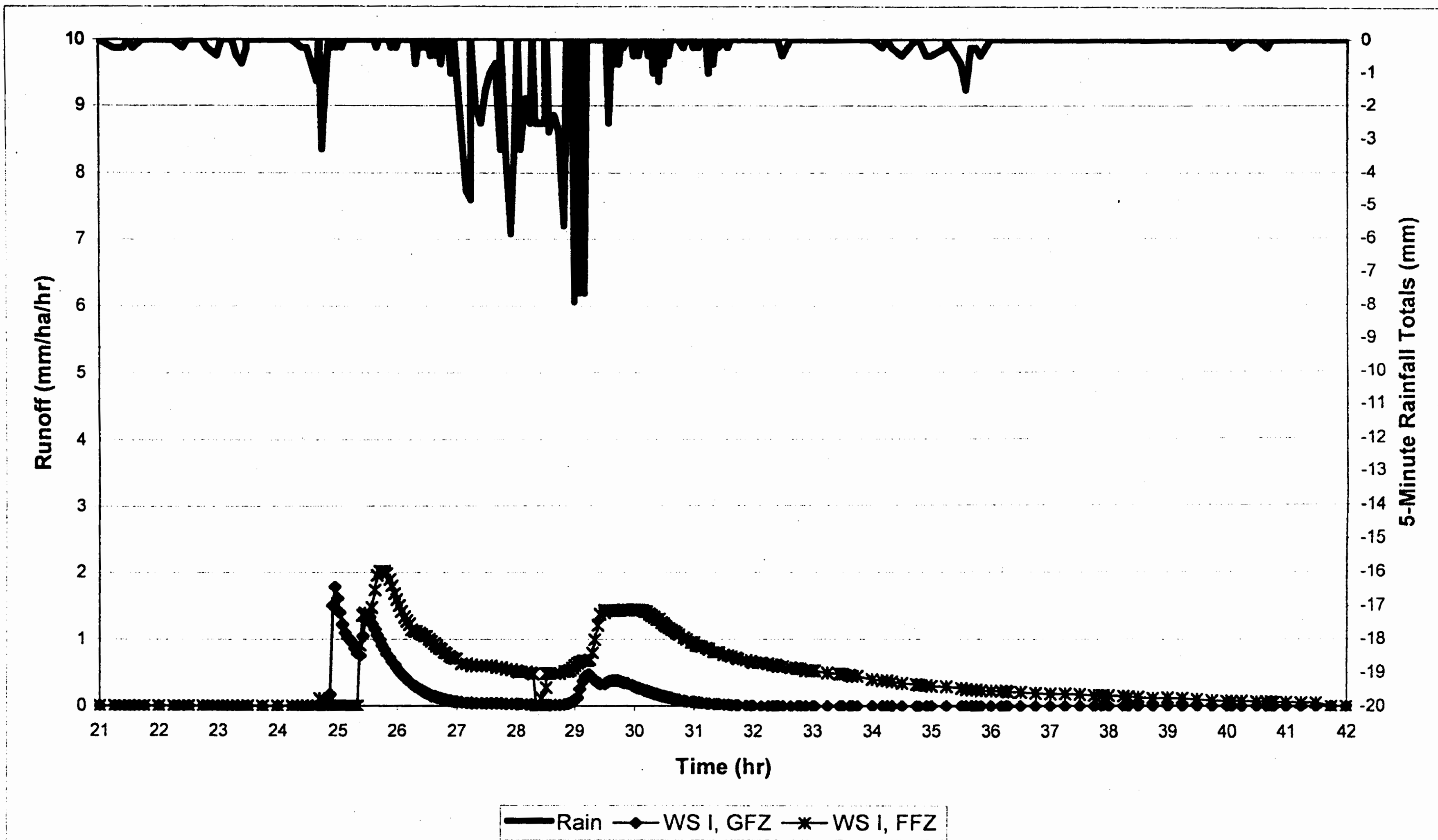

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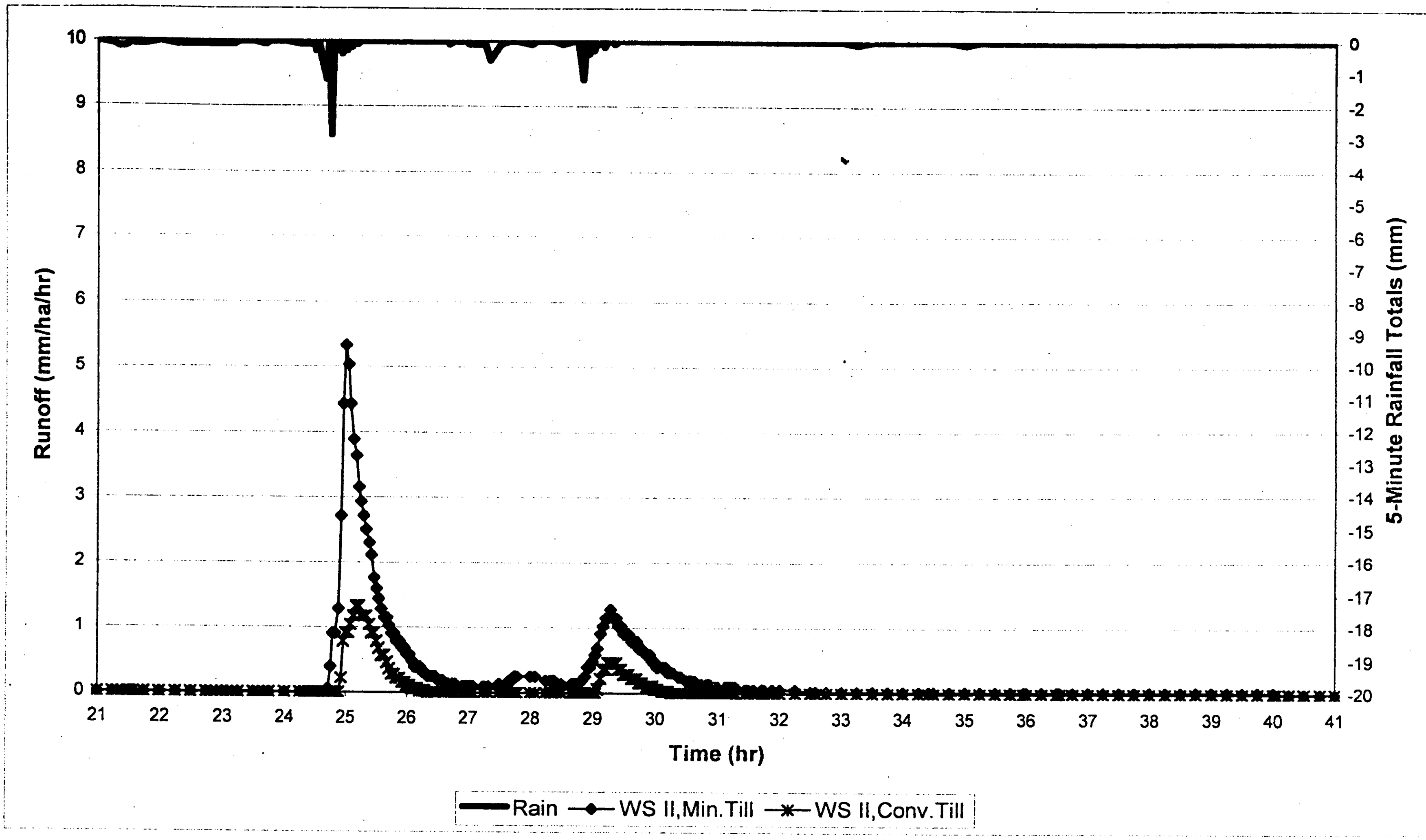

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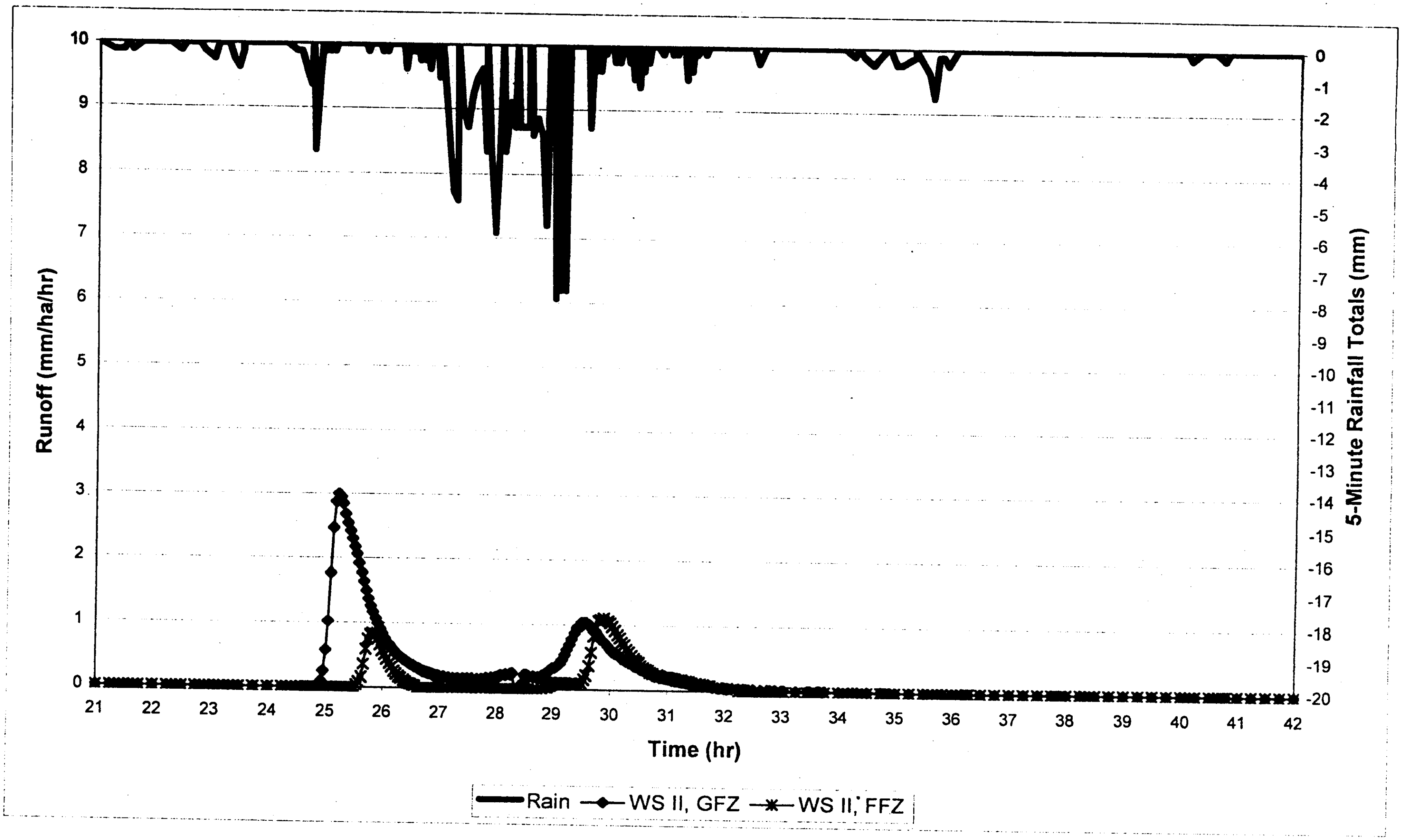

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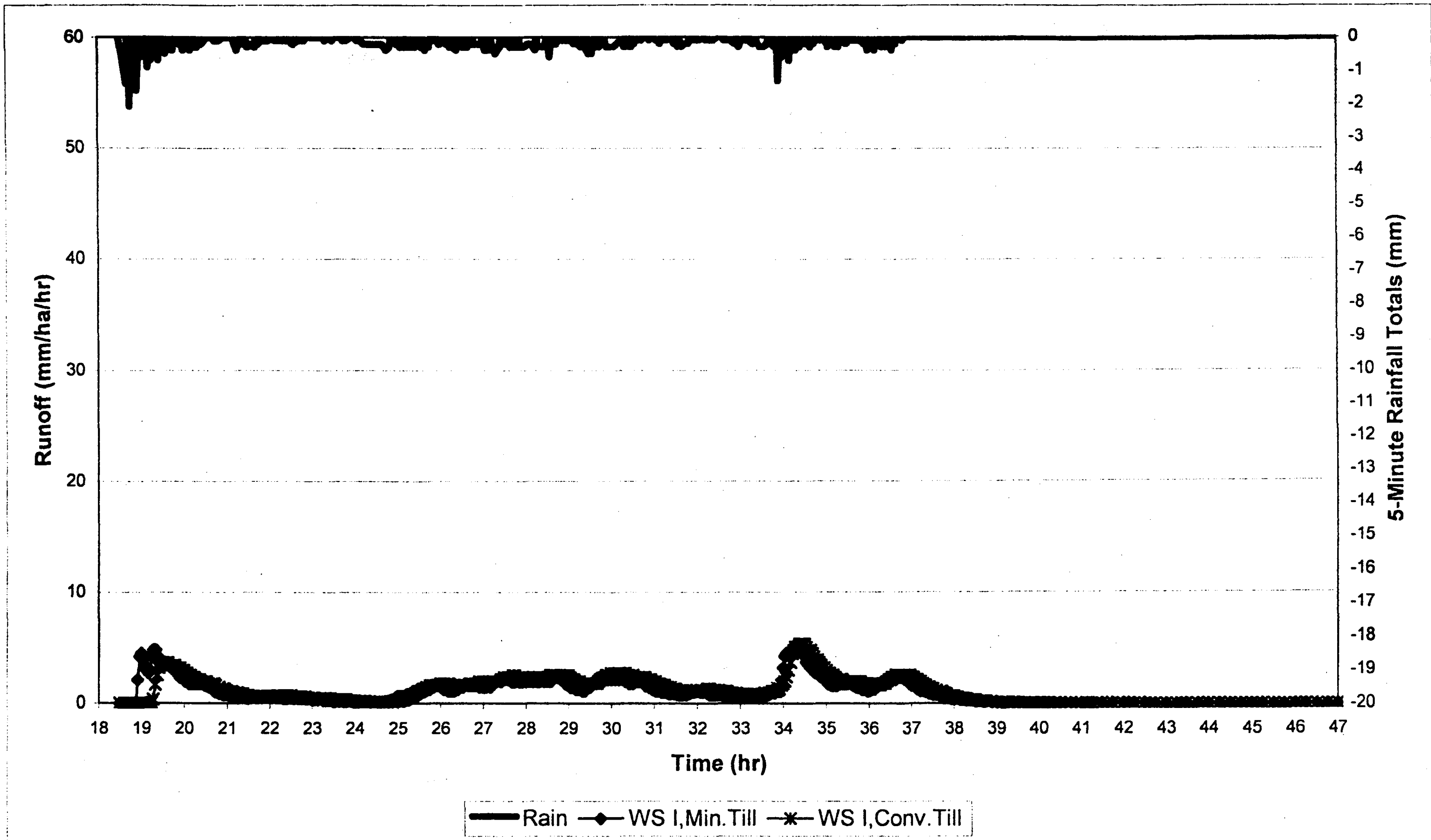
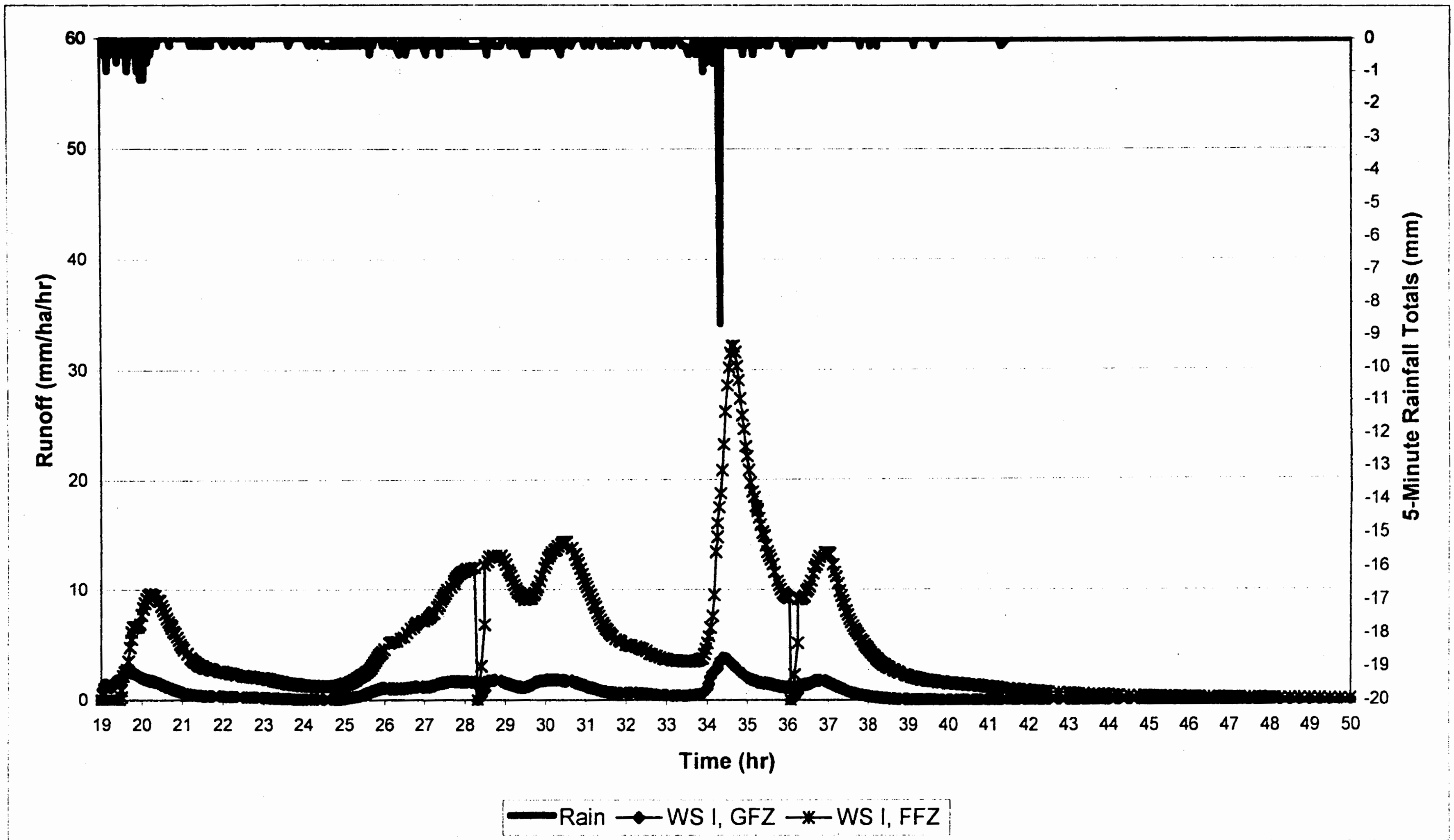


Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 23, 1999.



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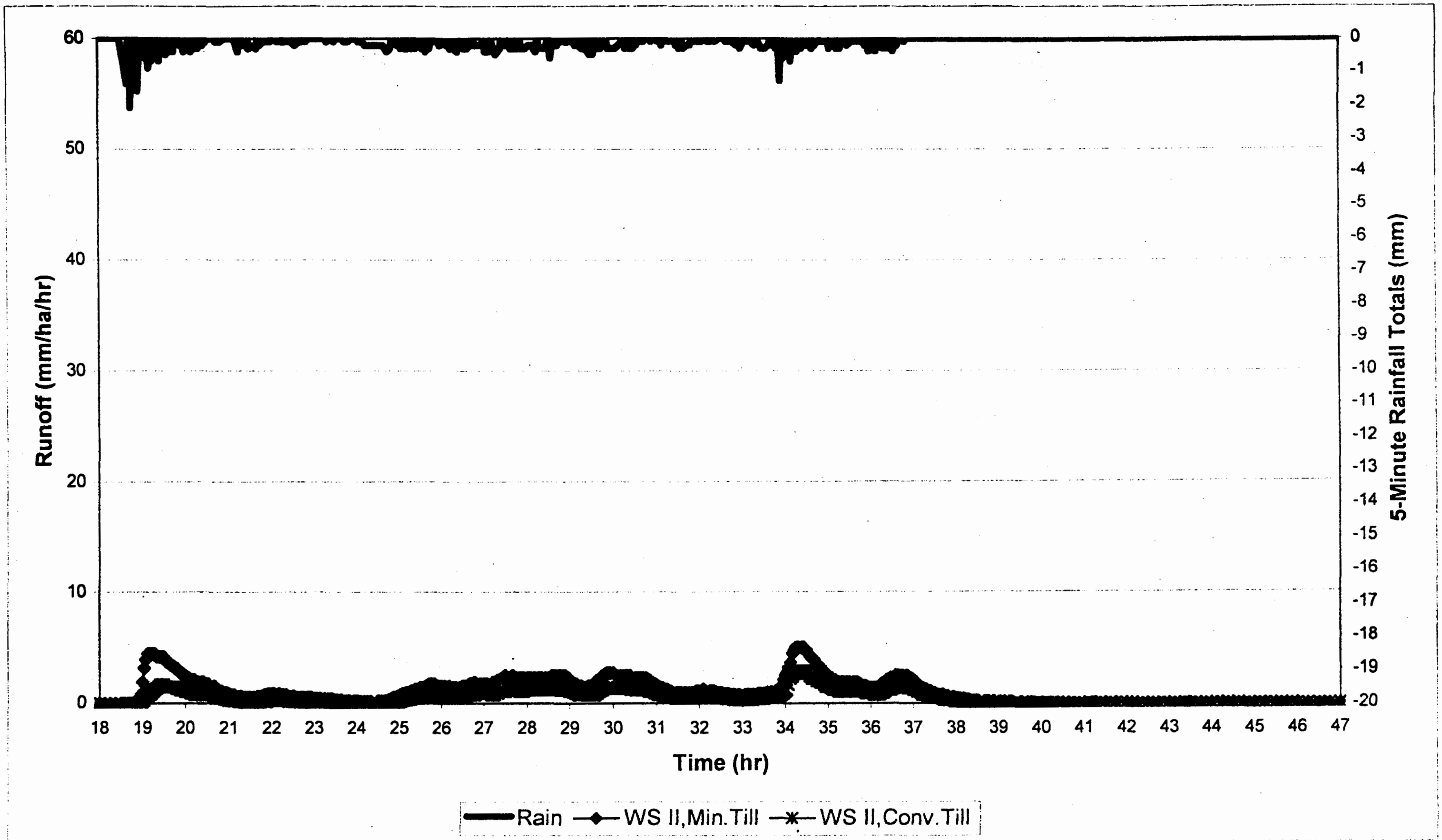

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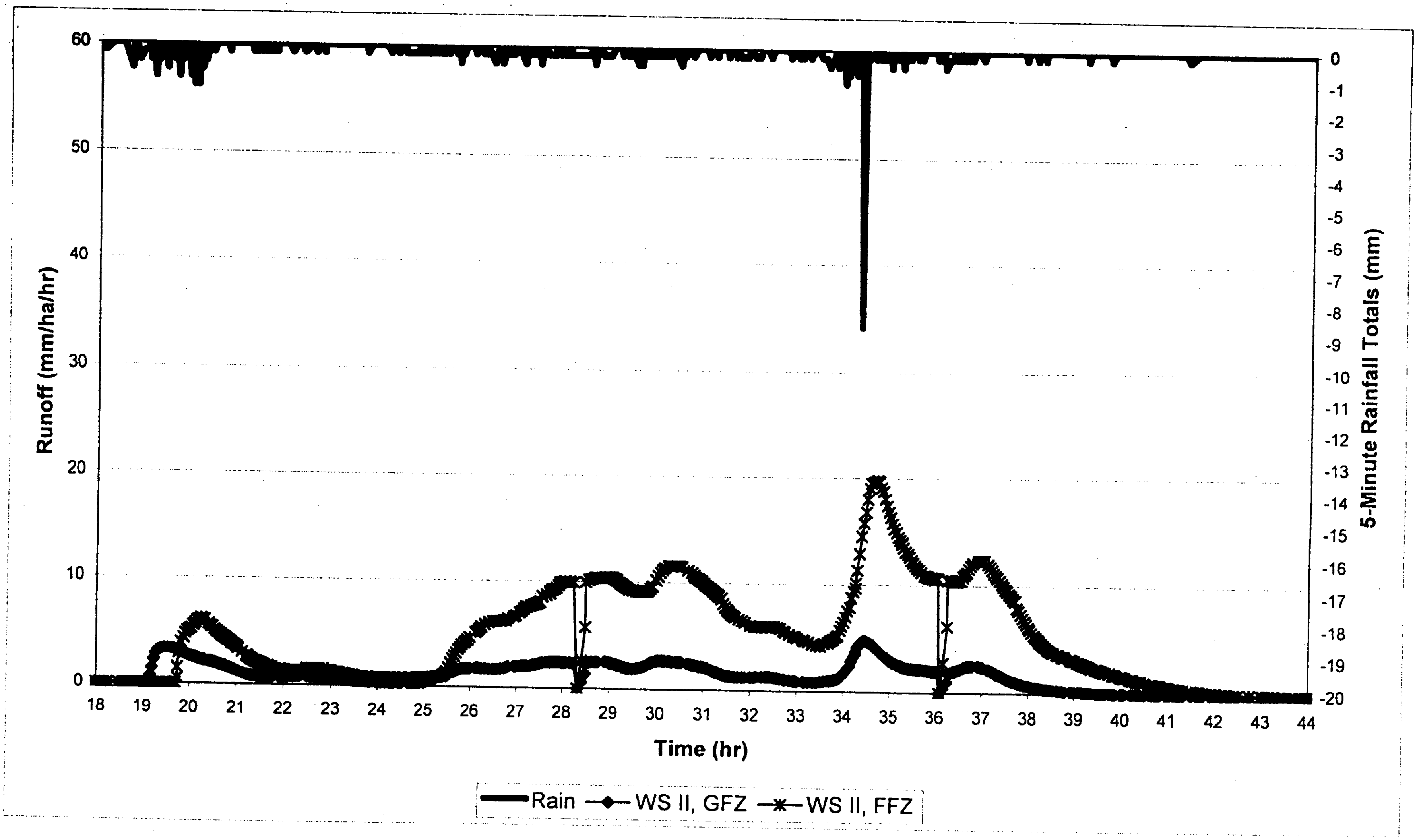

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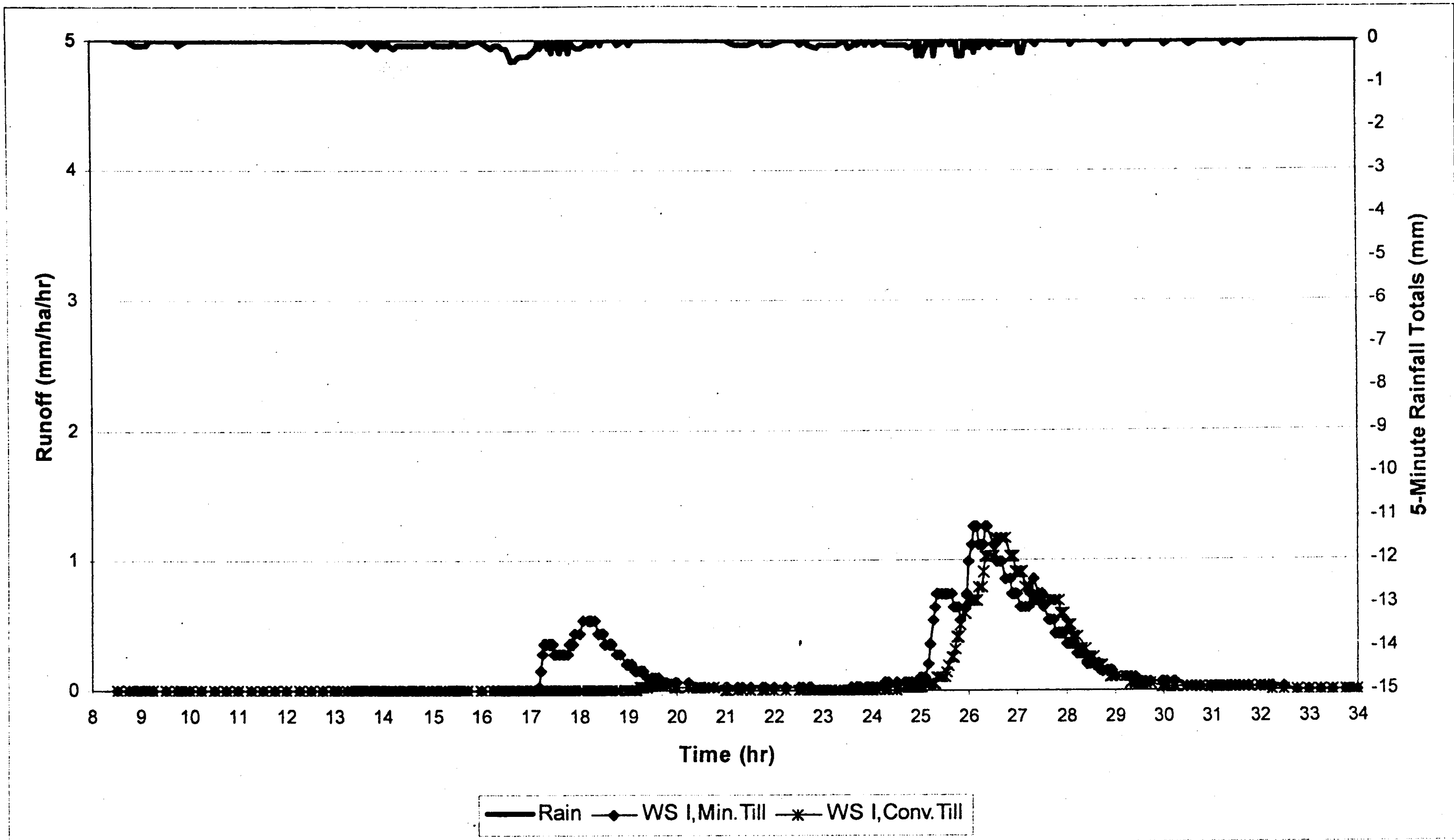

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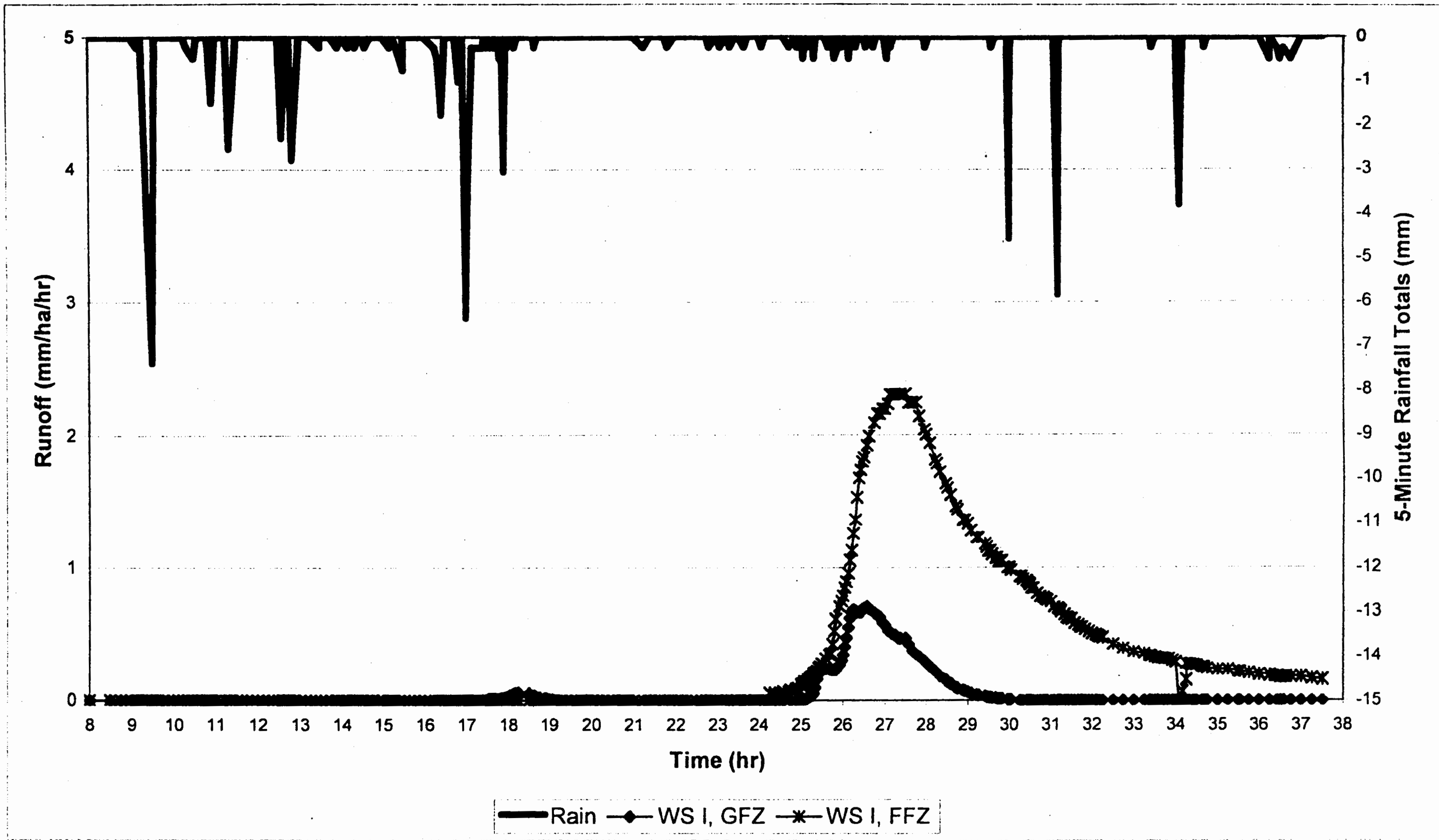
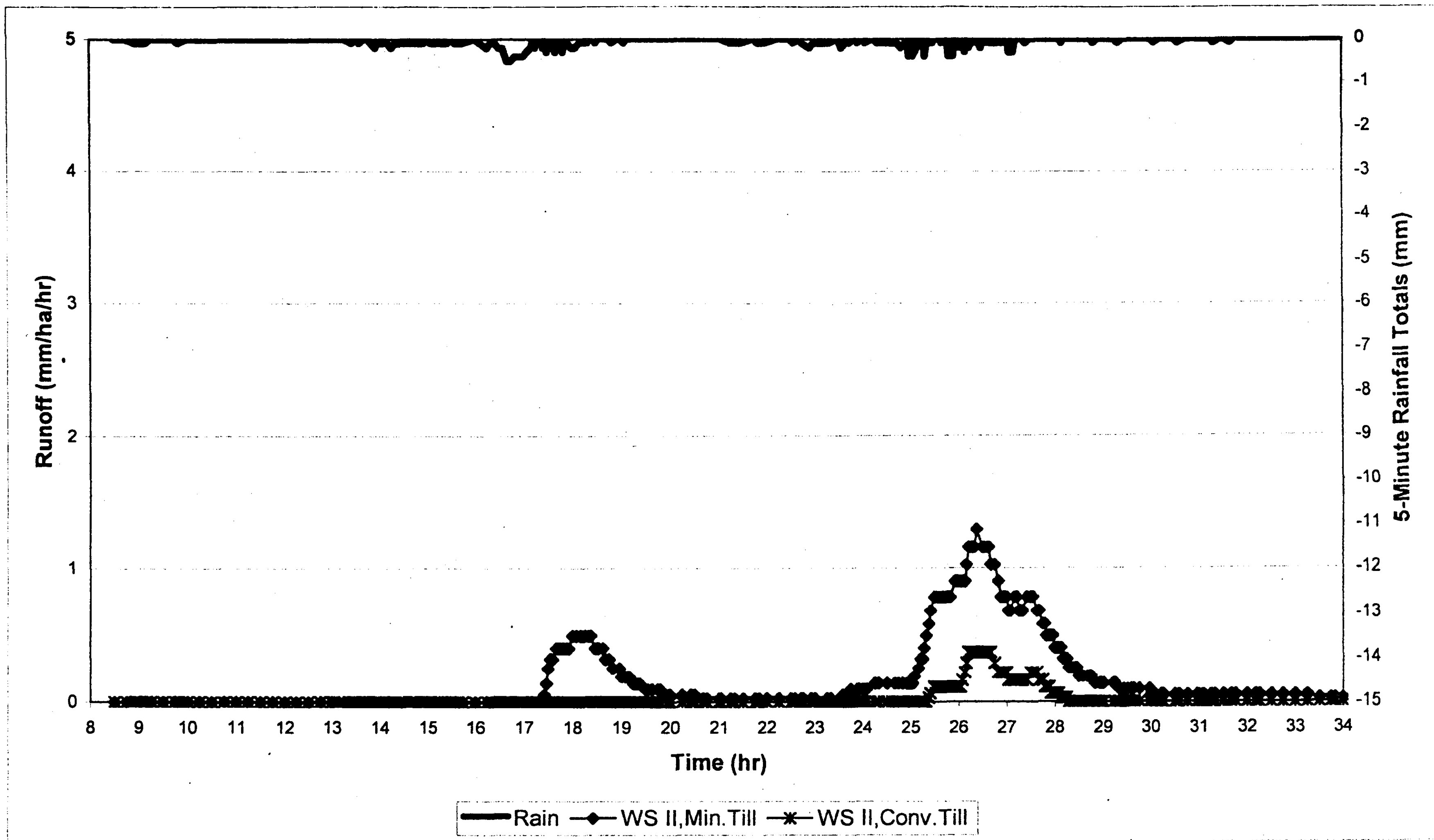


Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 32, 1999.



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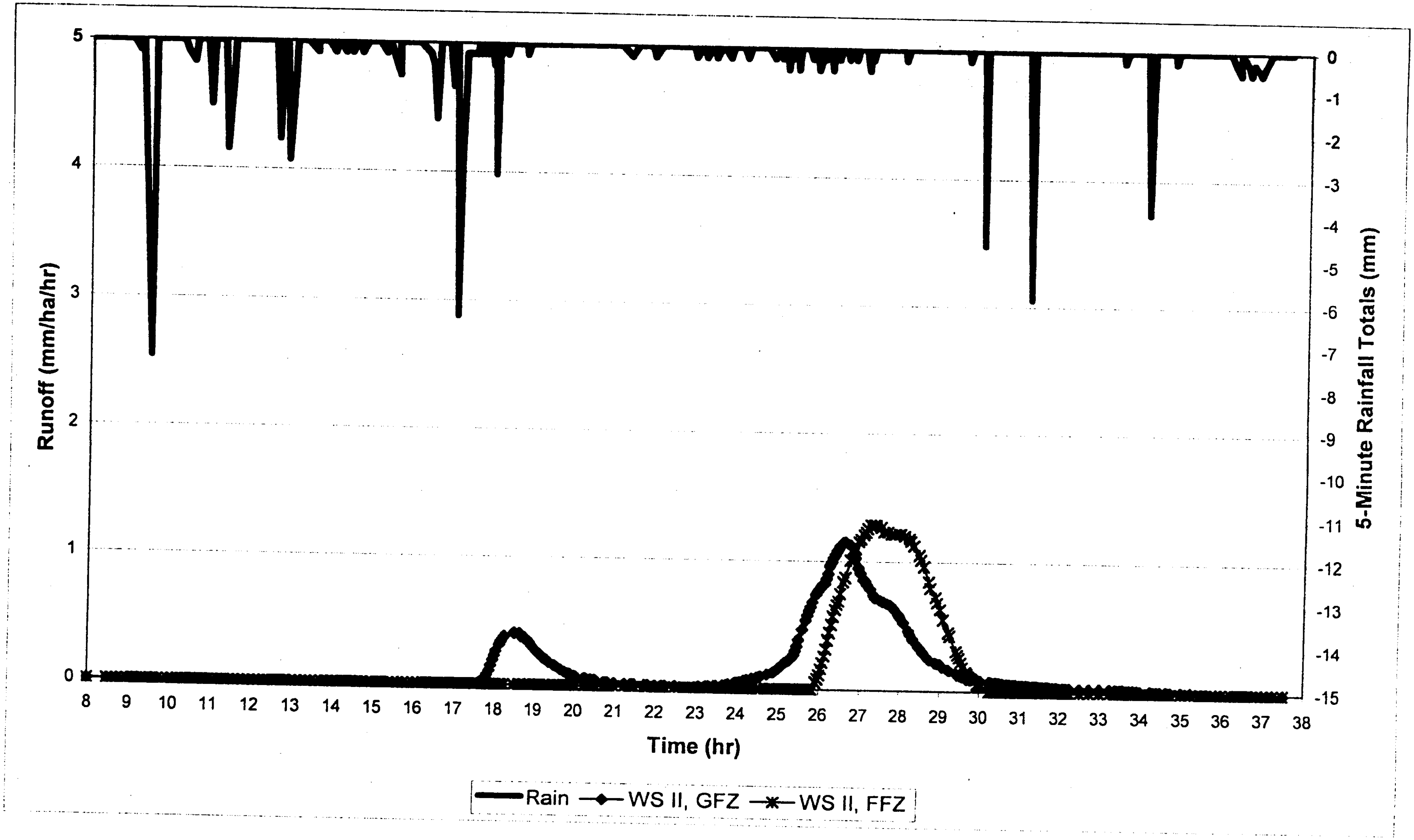
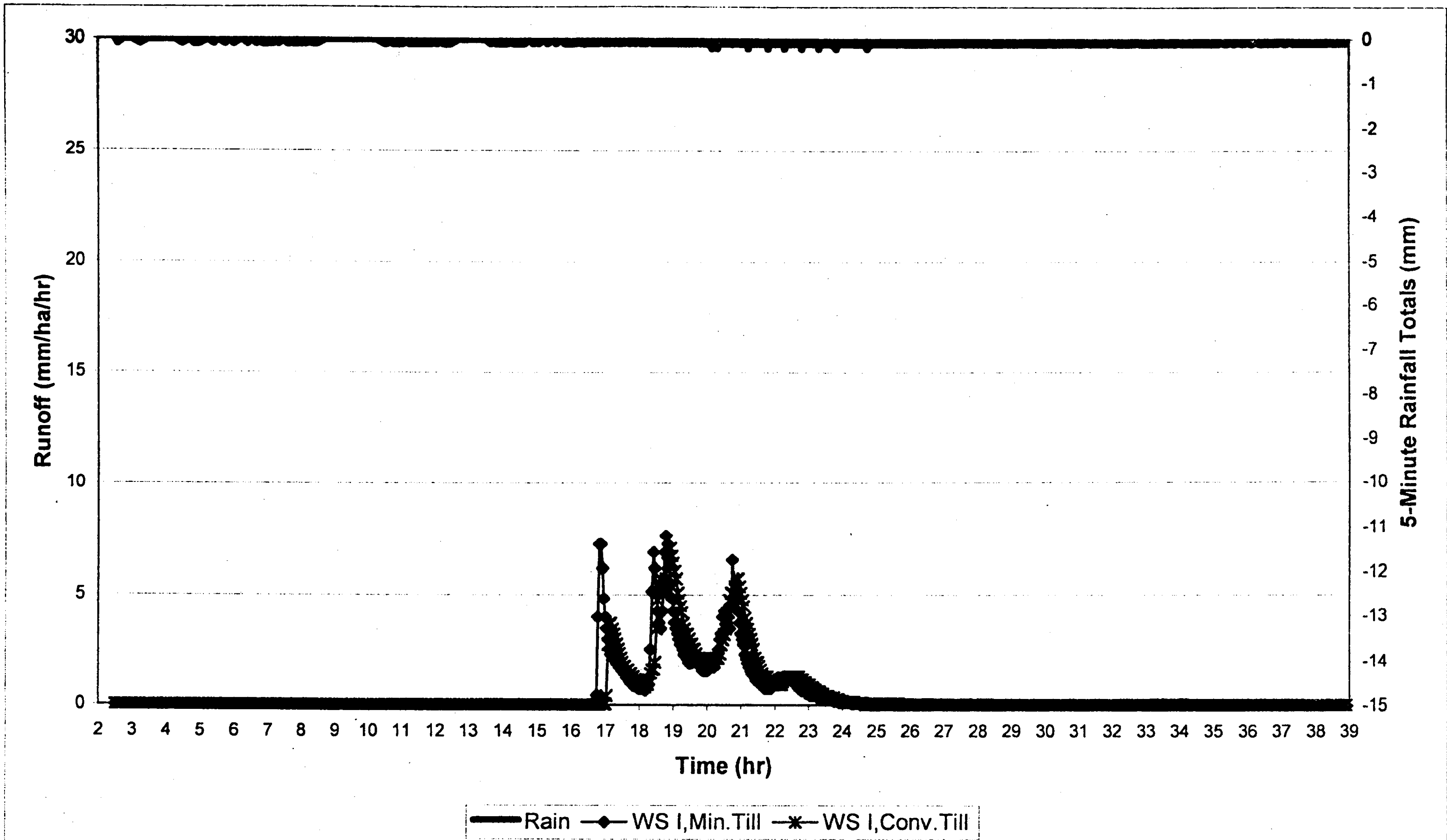
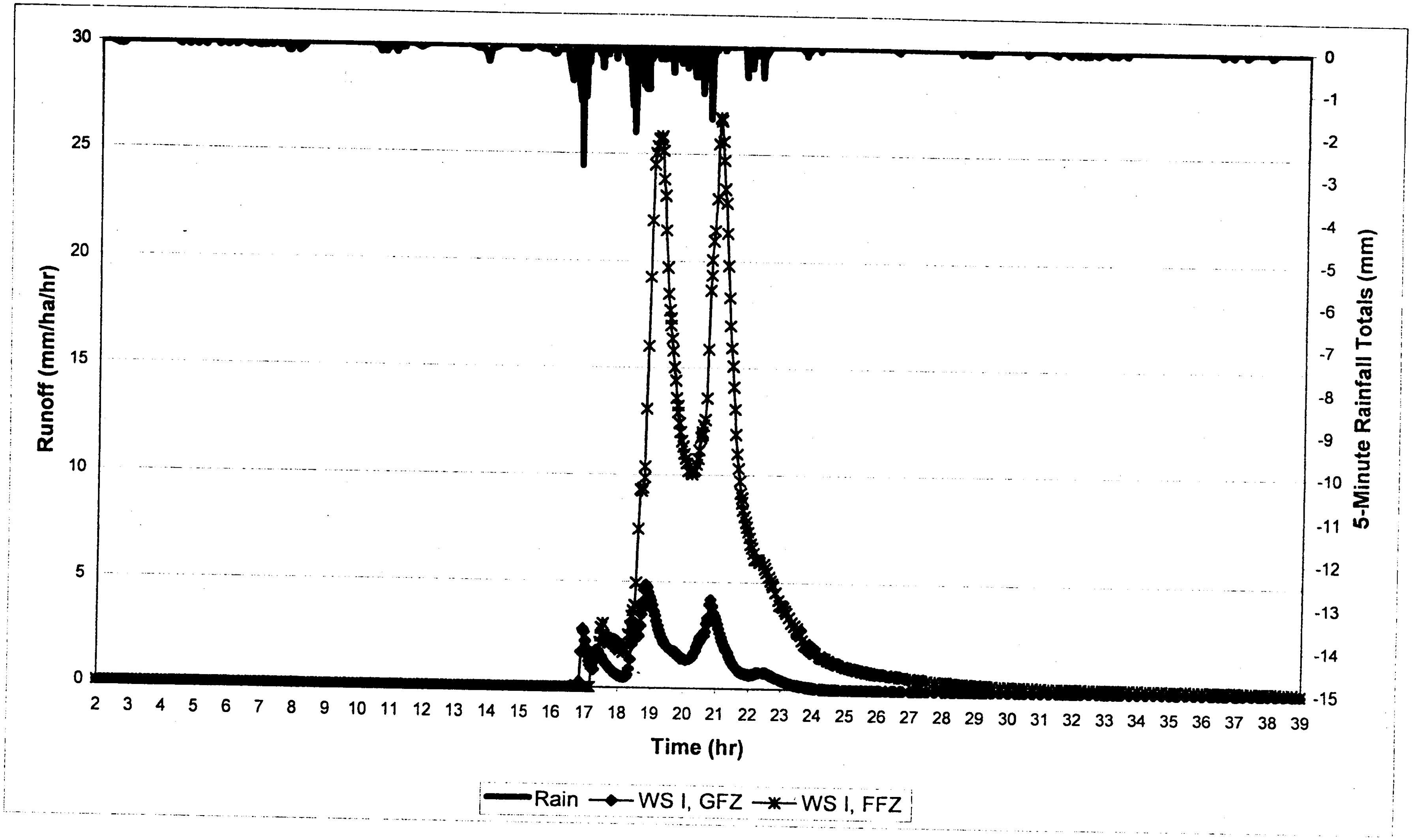


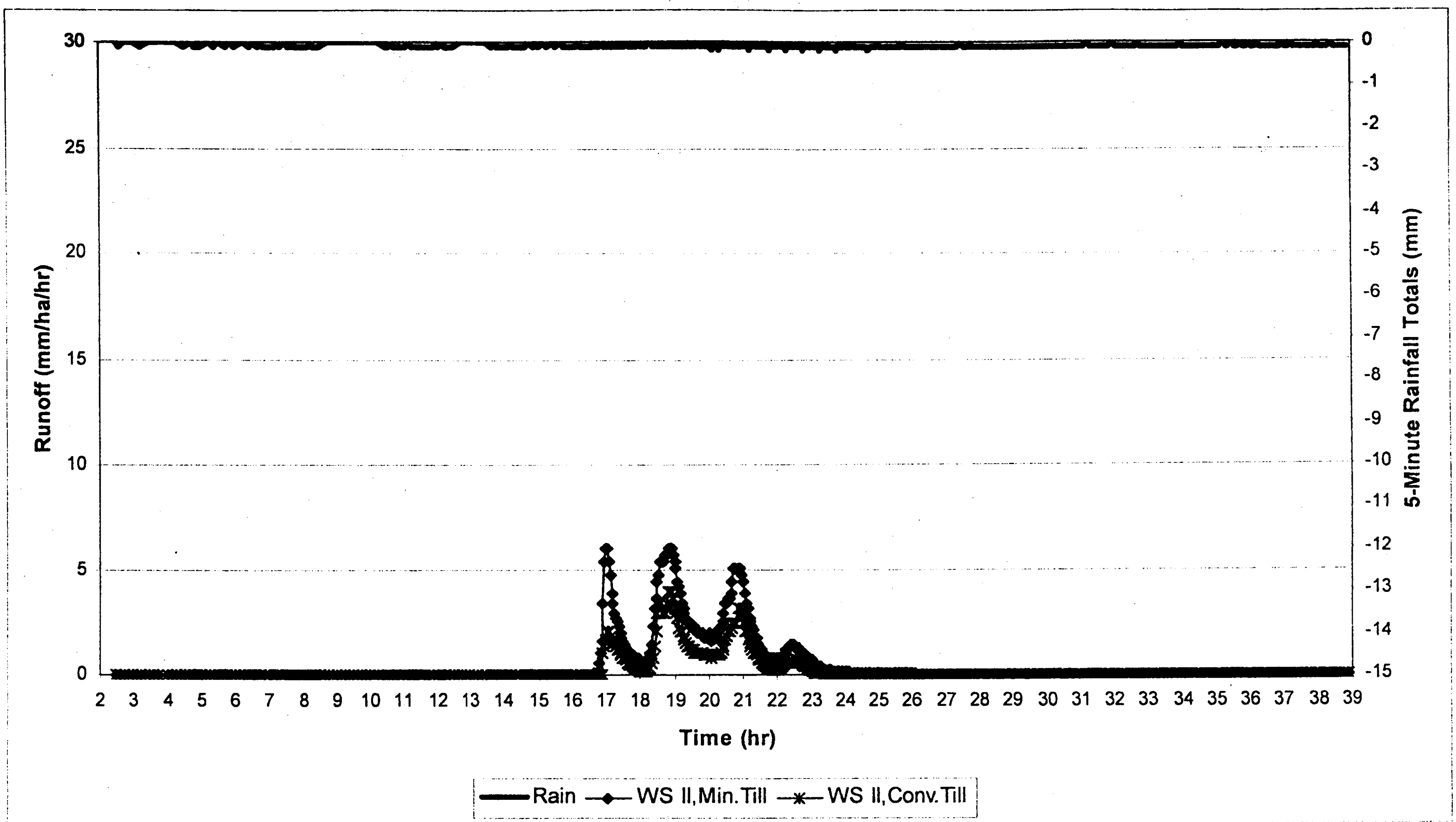
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 32, 1999.



Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 73, 1999.



Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 73, 1999.



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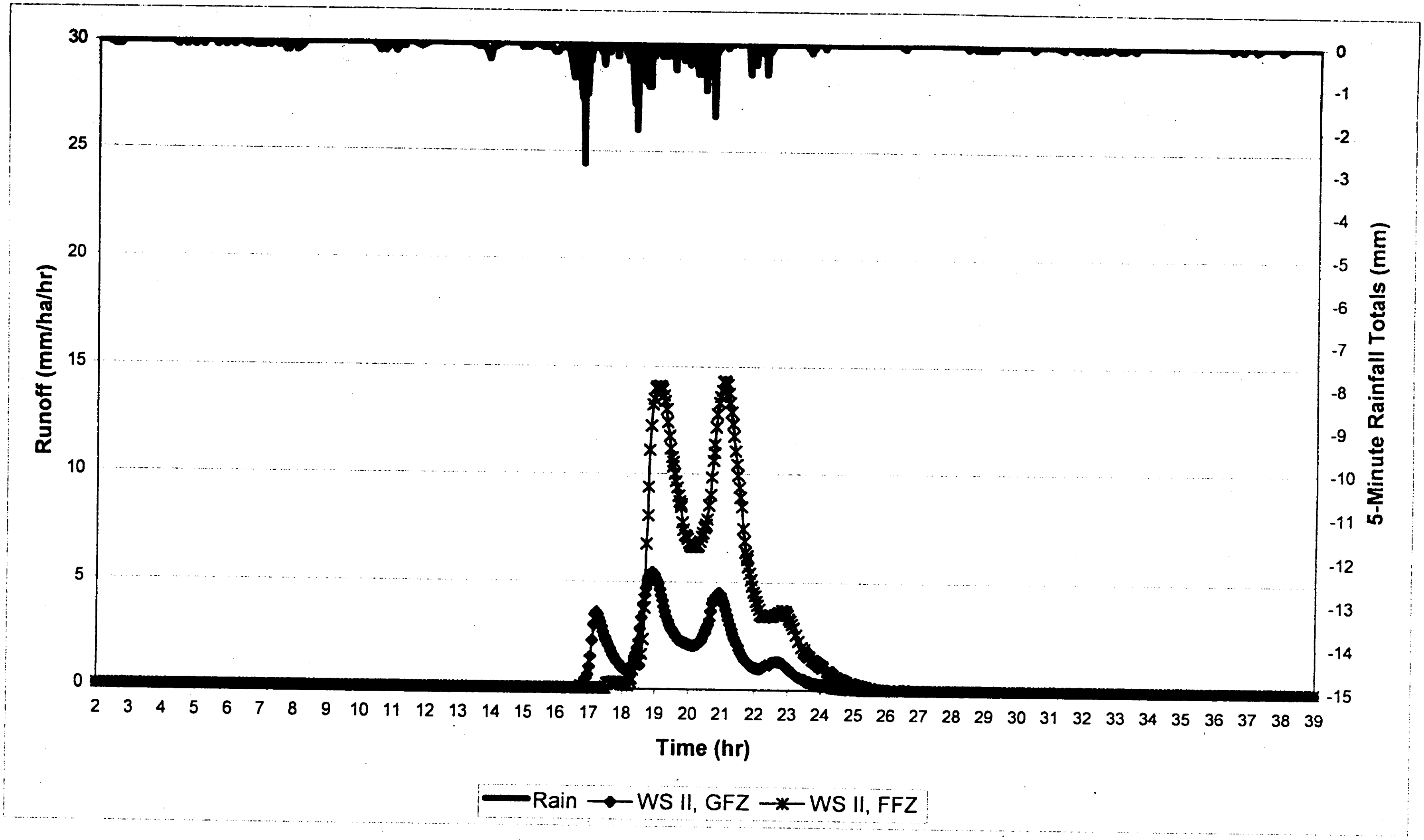

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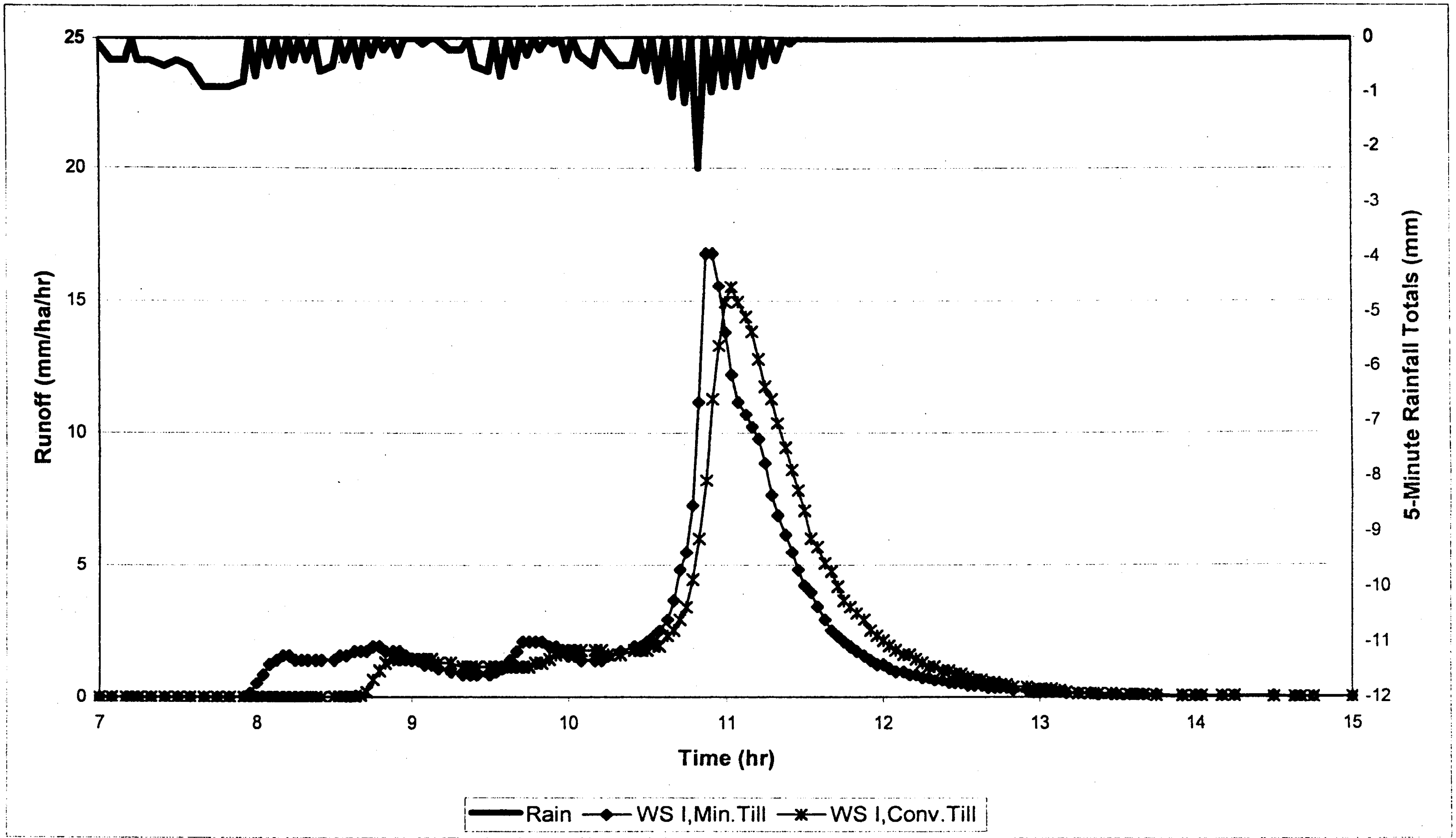

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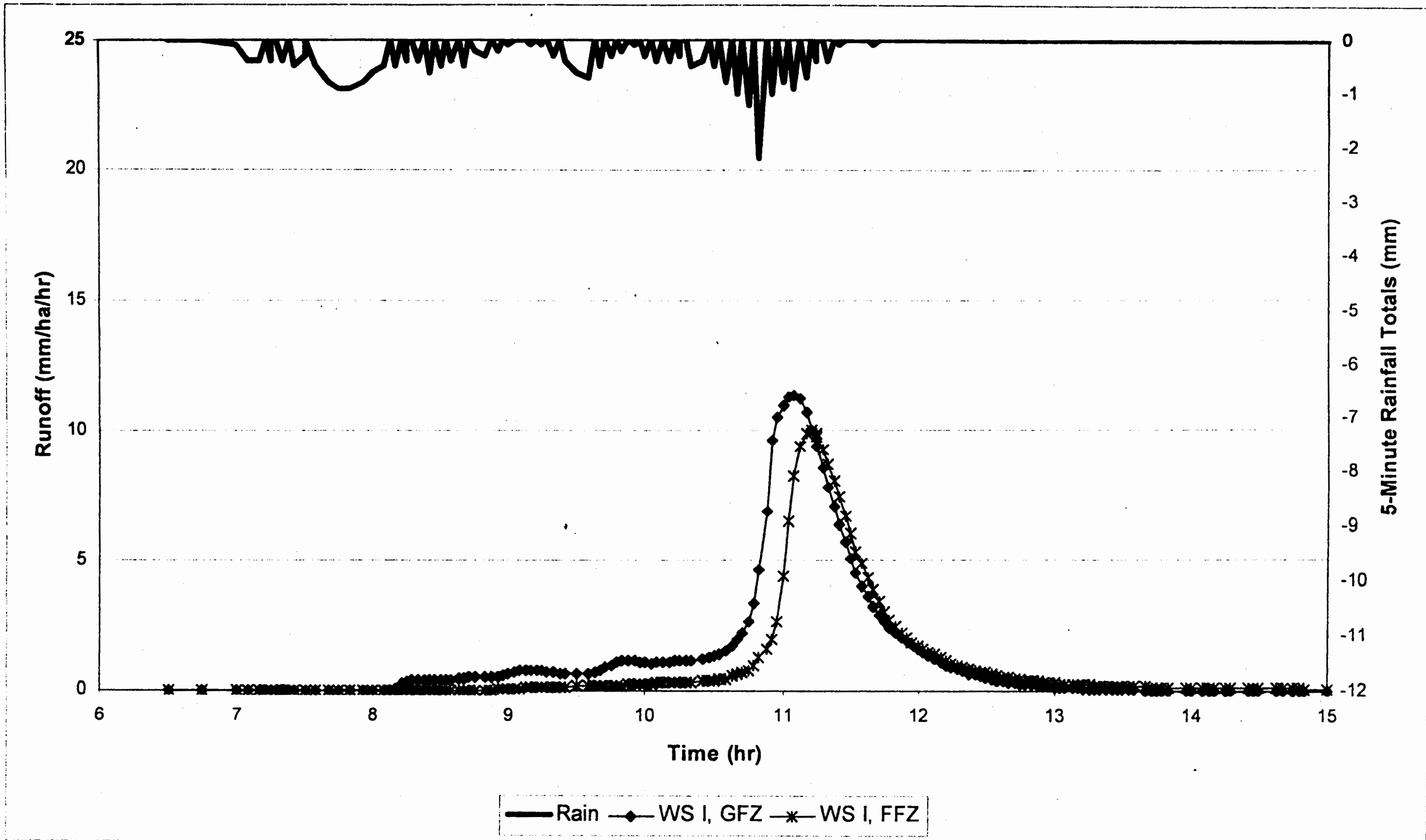

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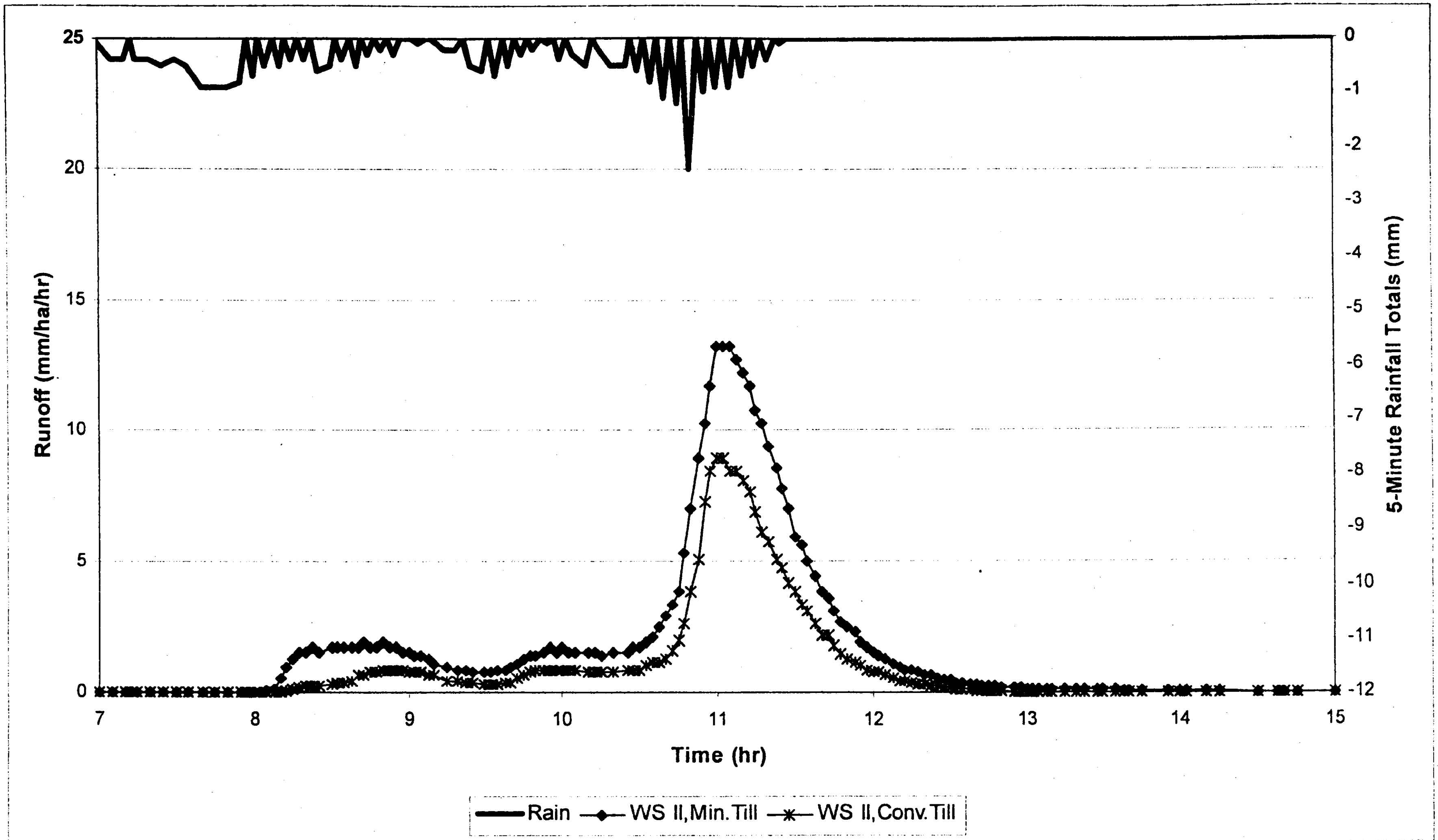

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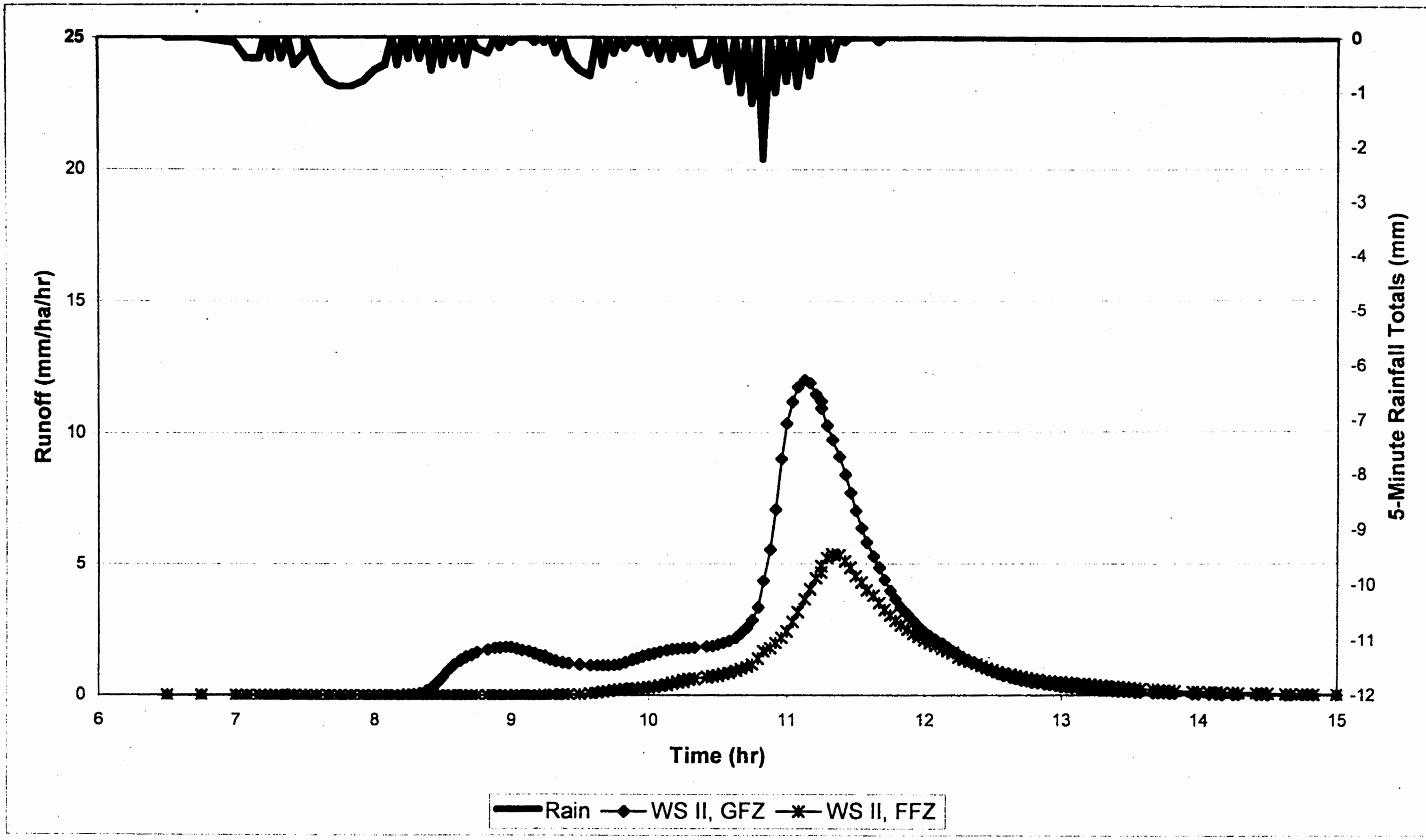
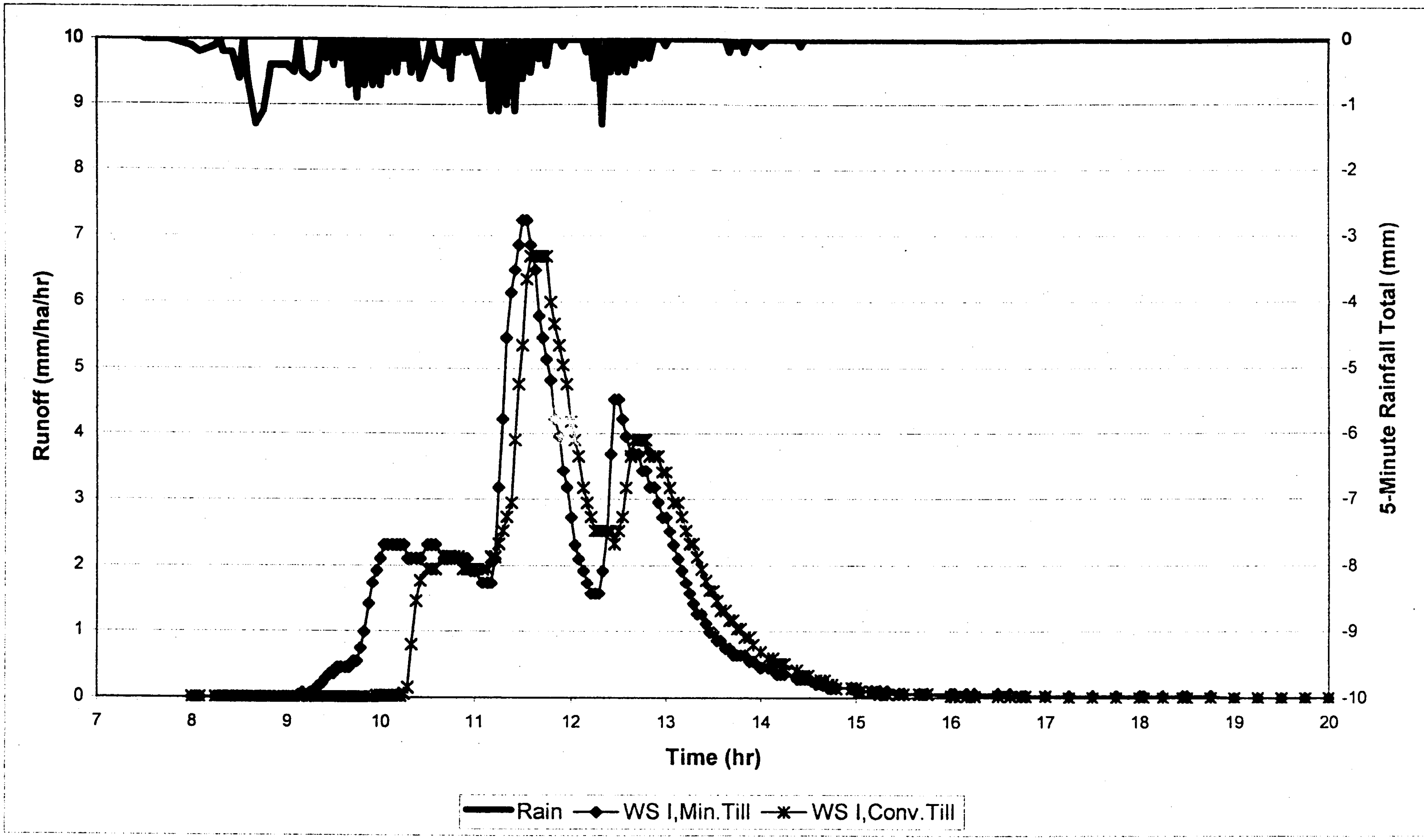
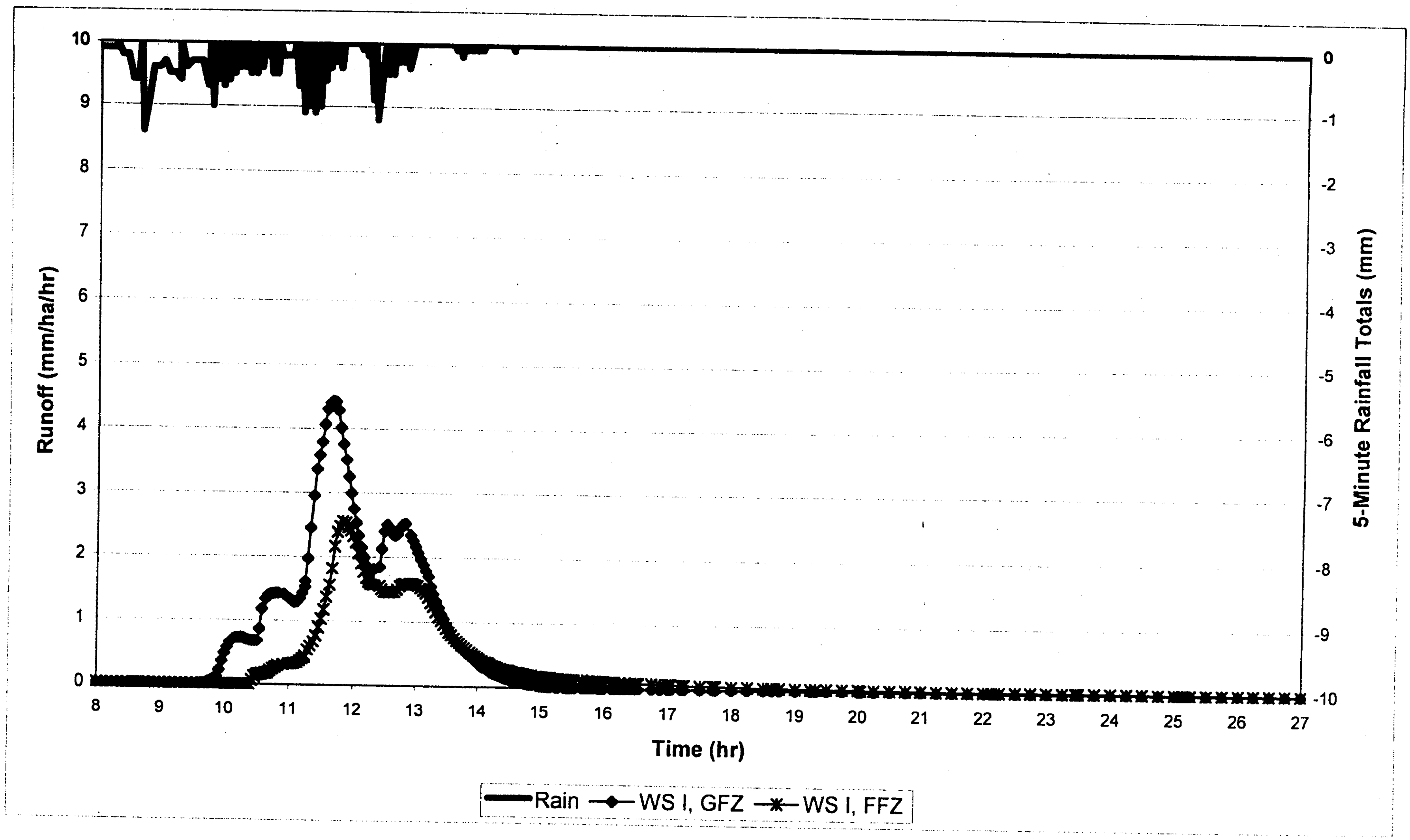


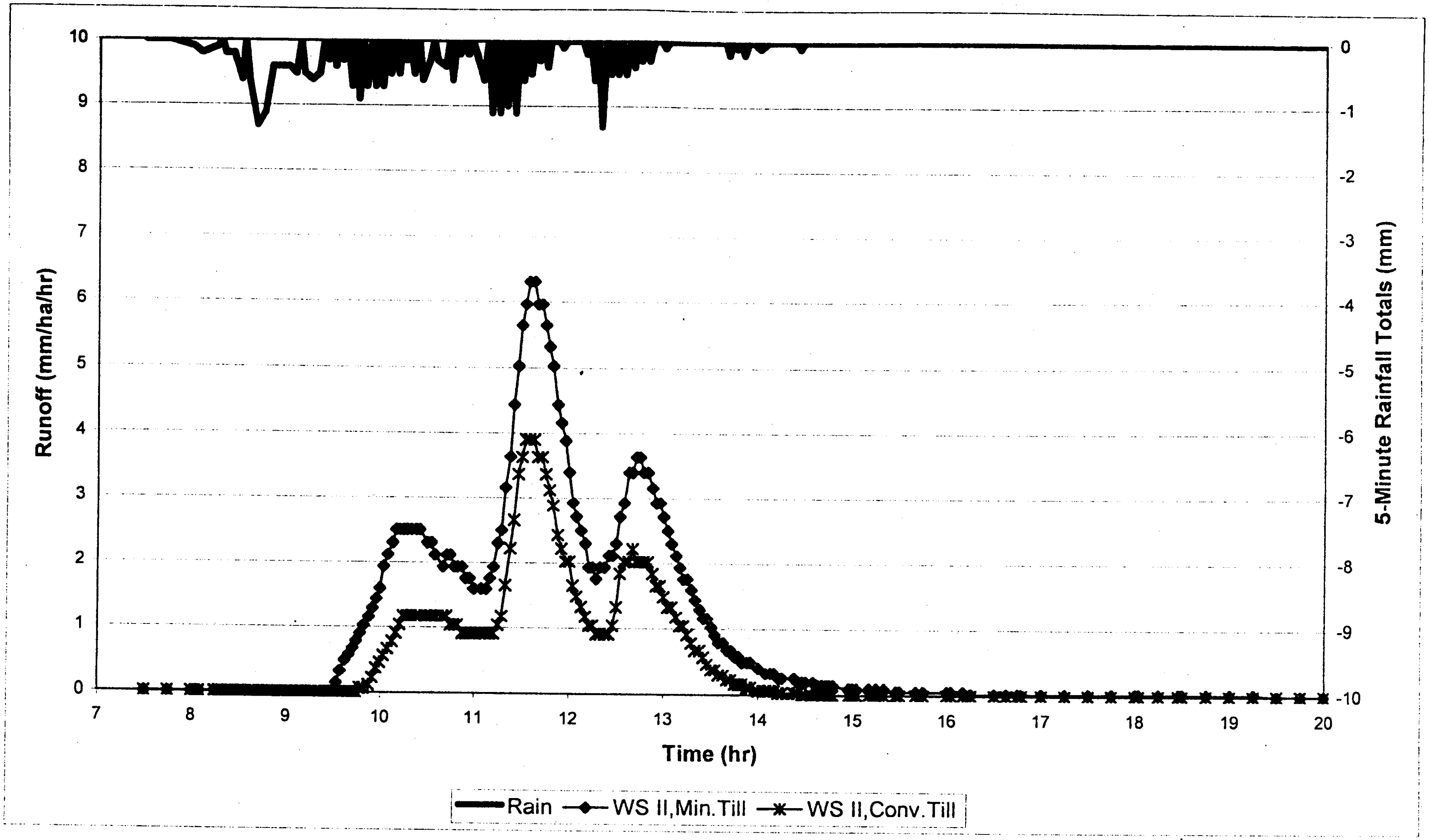
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 80, 1999.



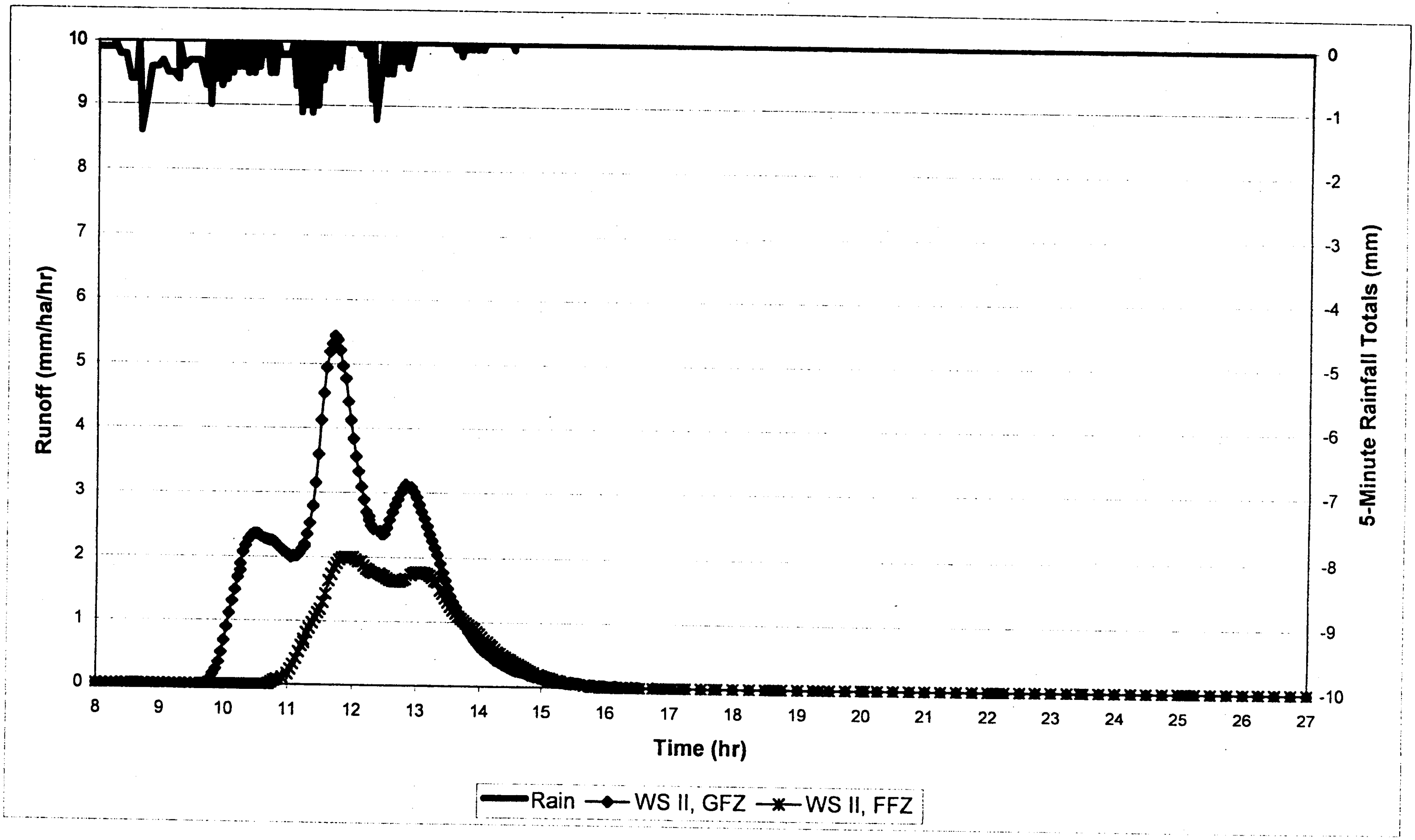
Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 91, 1999.



Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 91, 1999.



Storm Hydrograph for Oxford Tobacco Fields, Watershed II. Julian Day 91, 1999.



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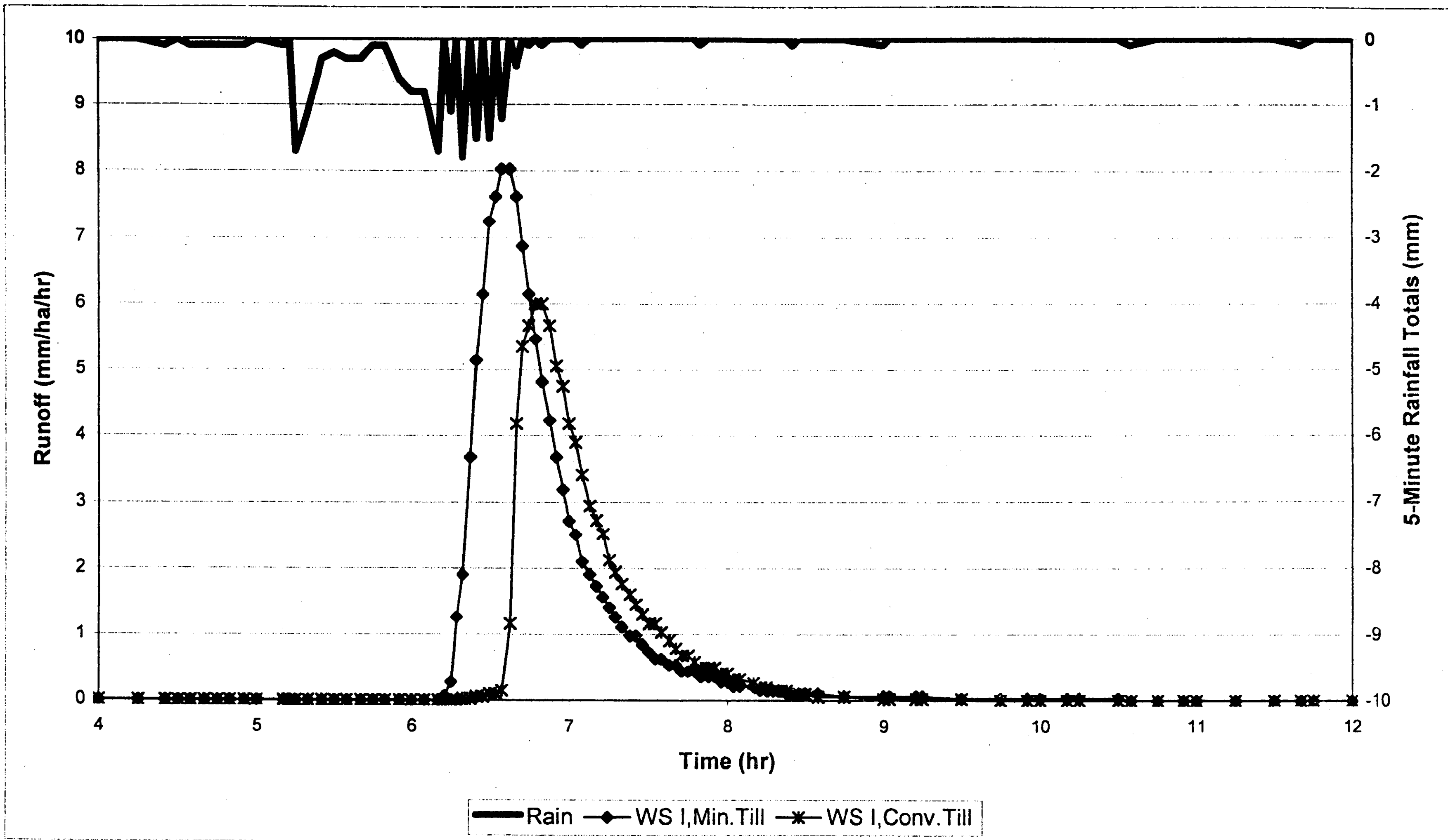

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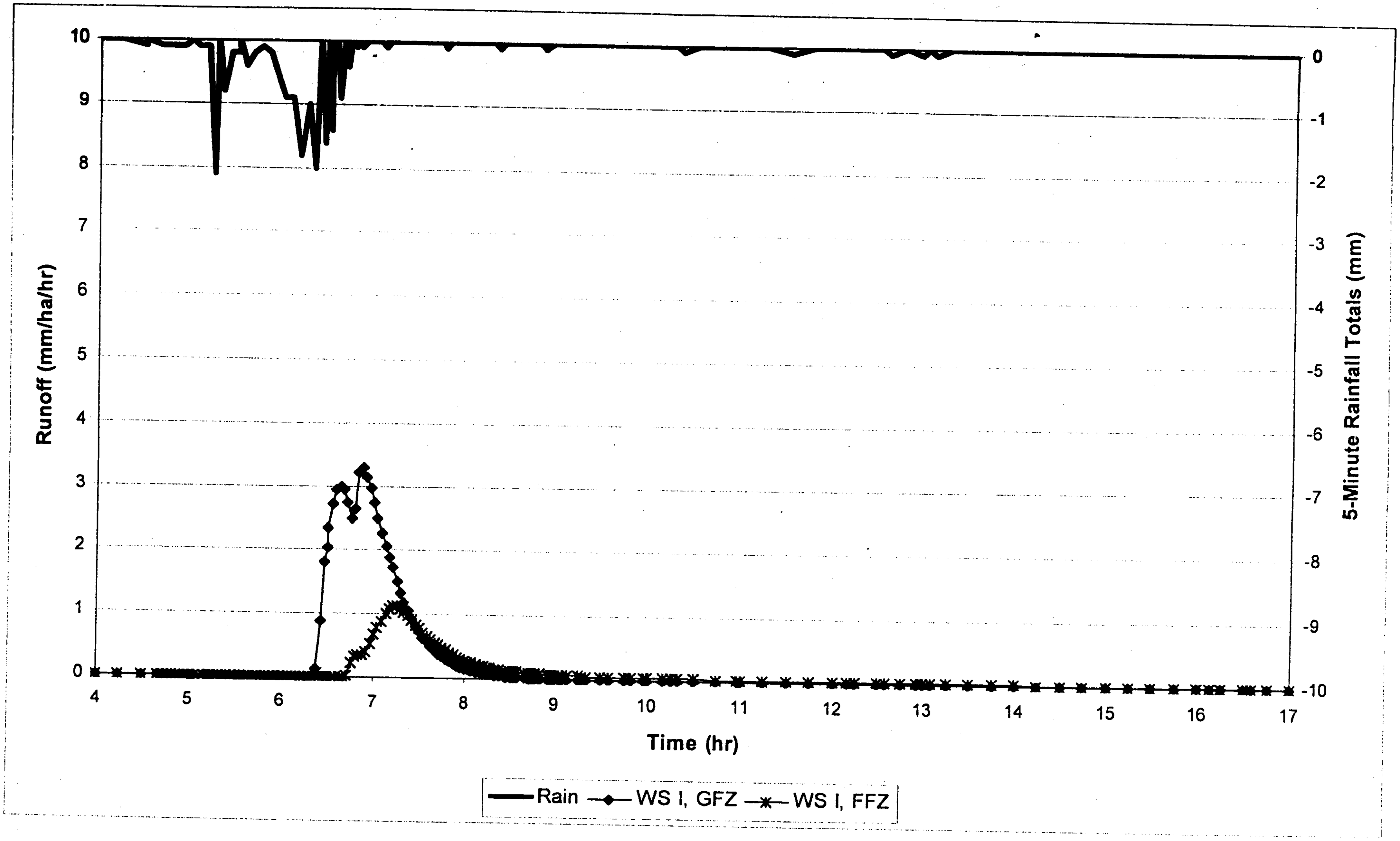

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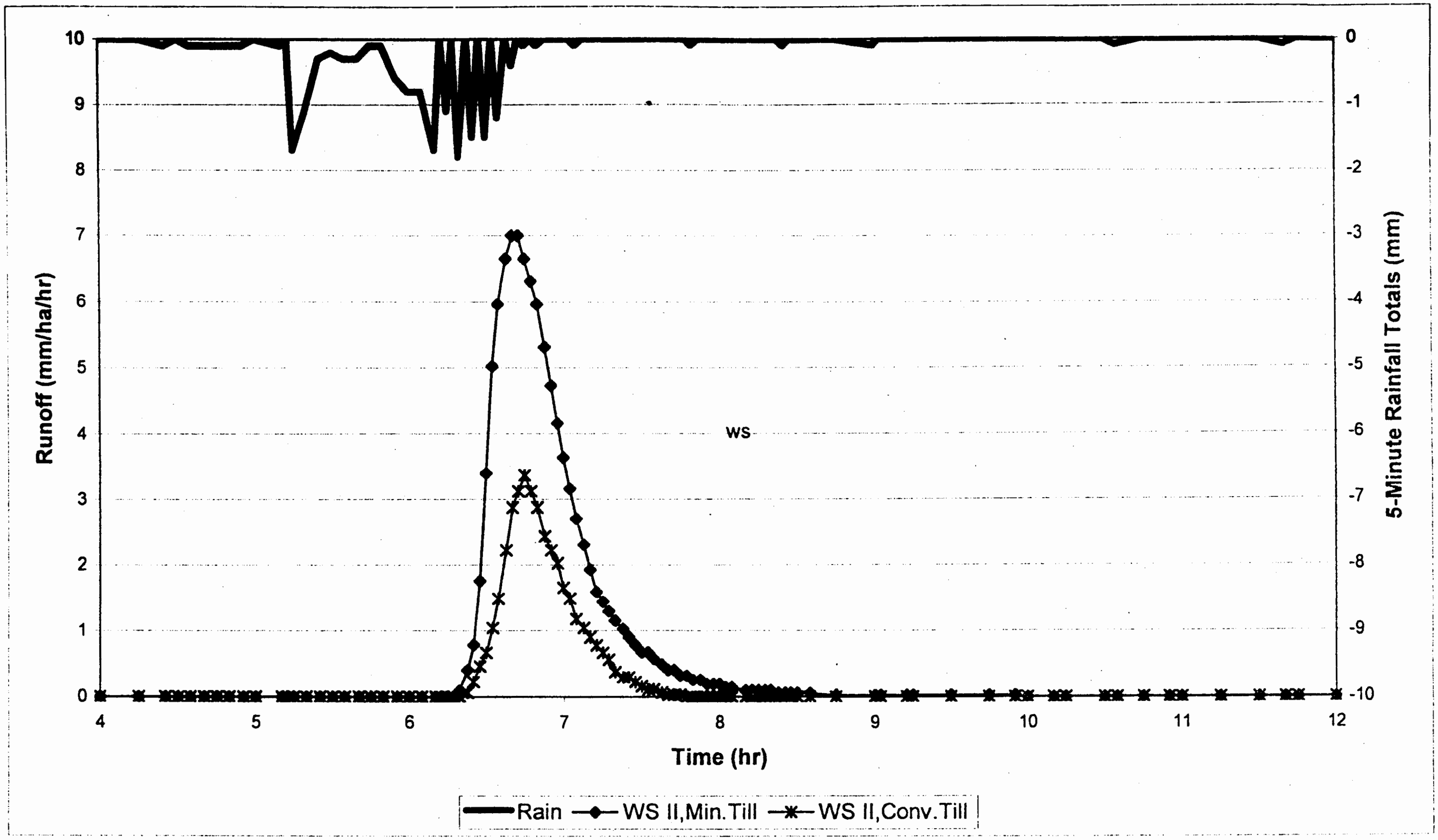

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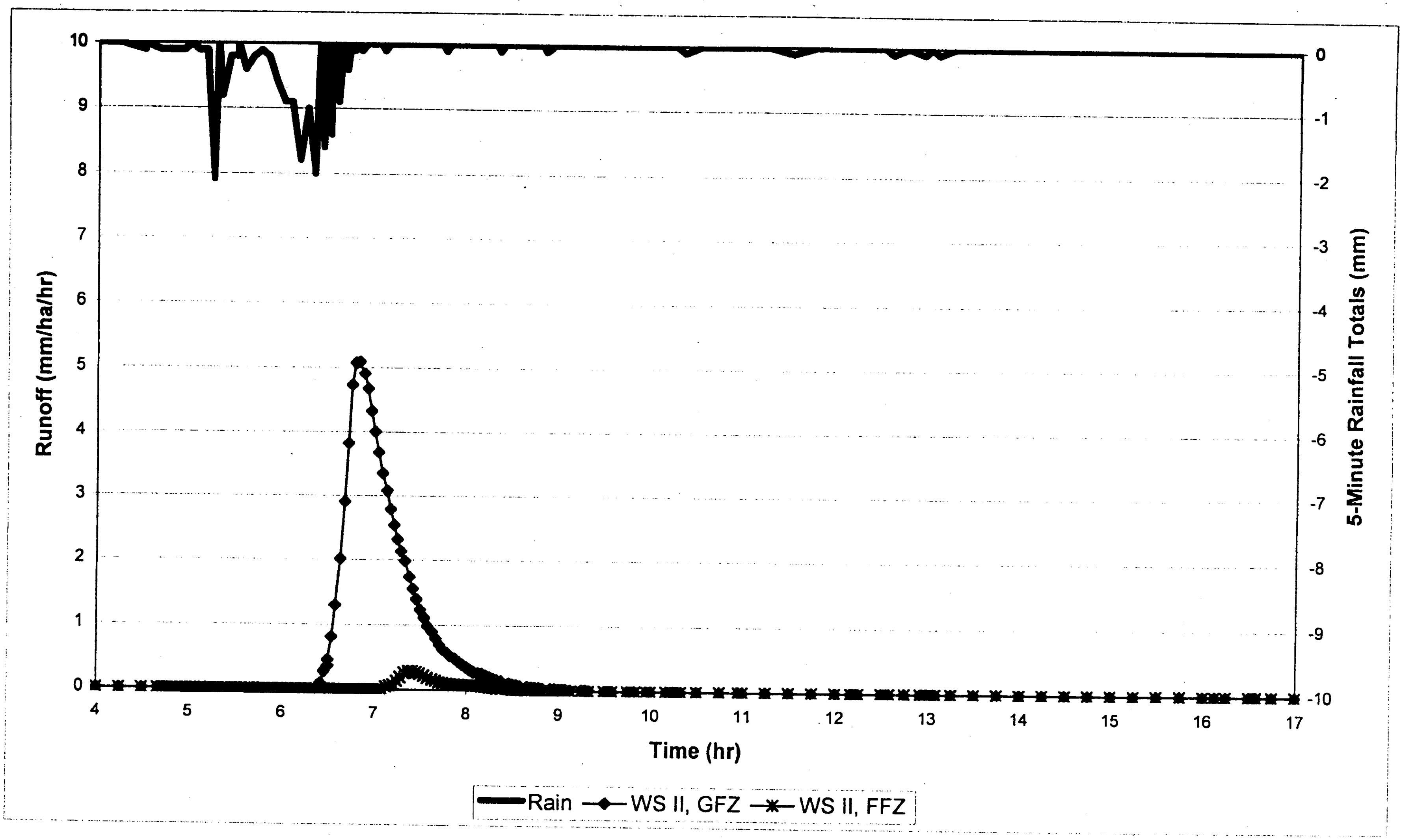

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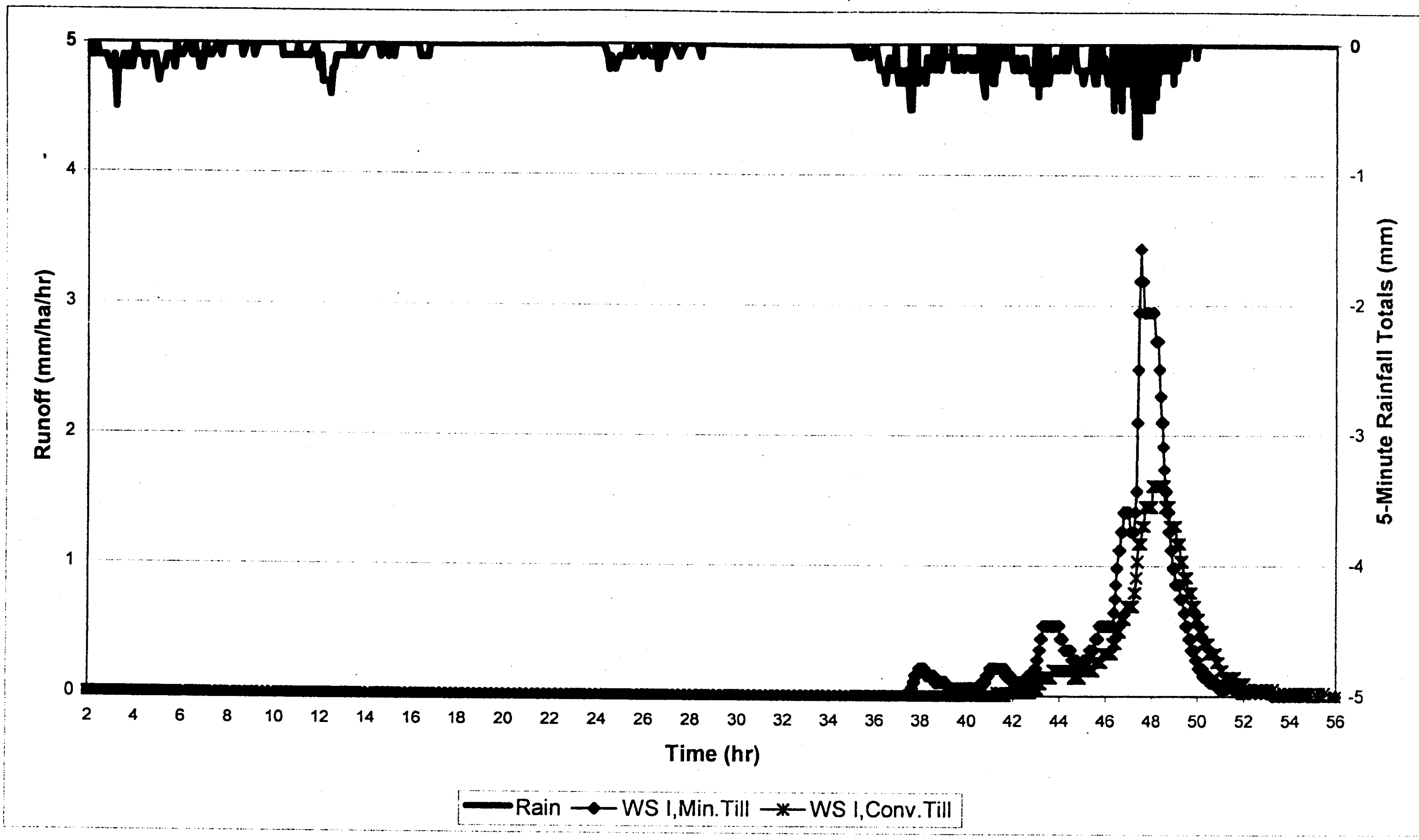

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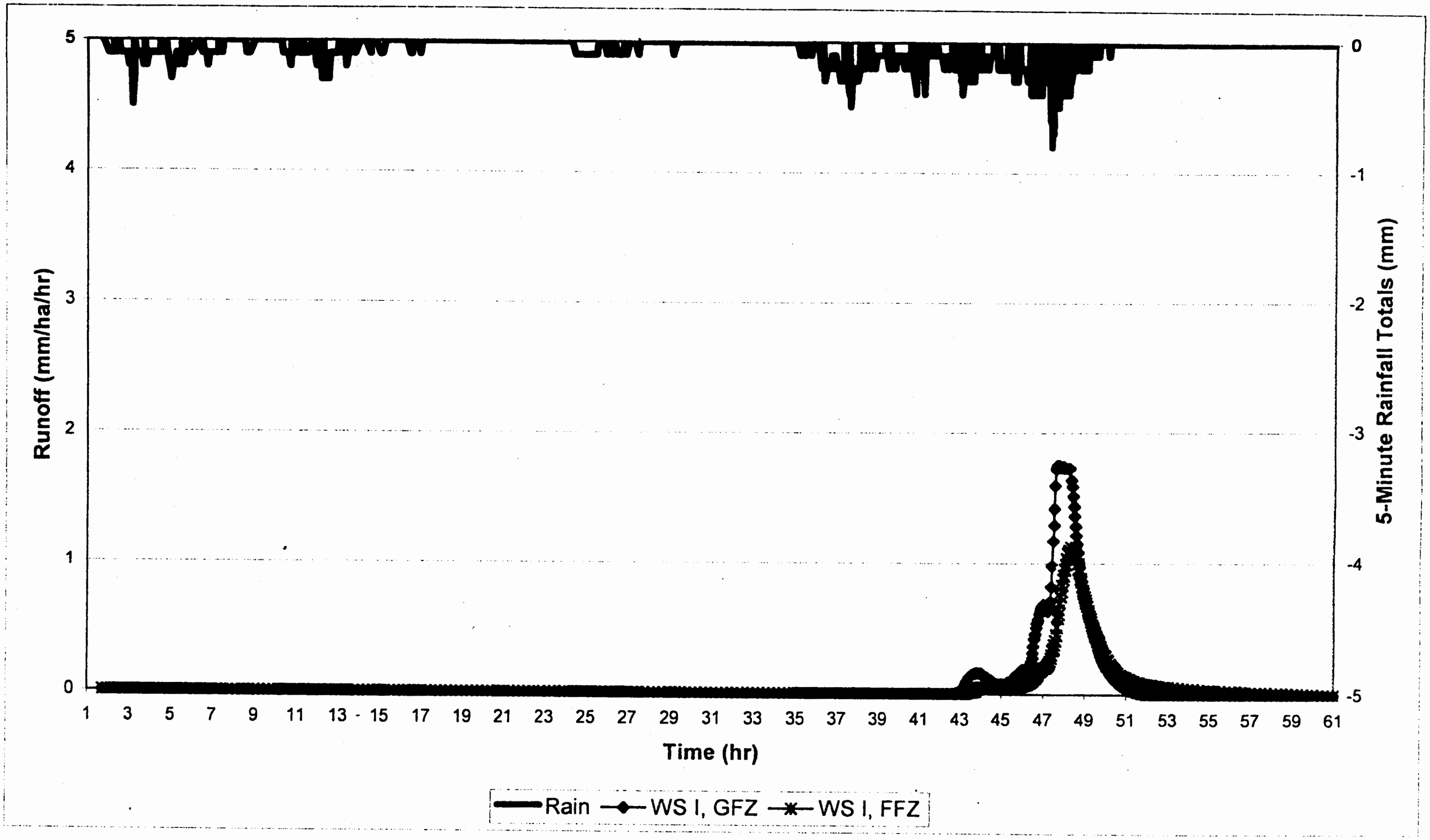

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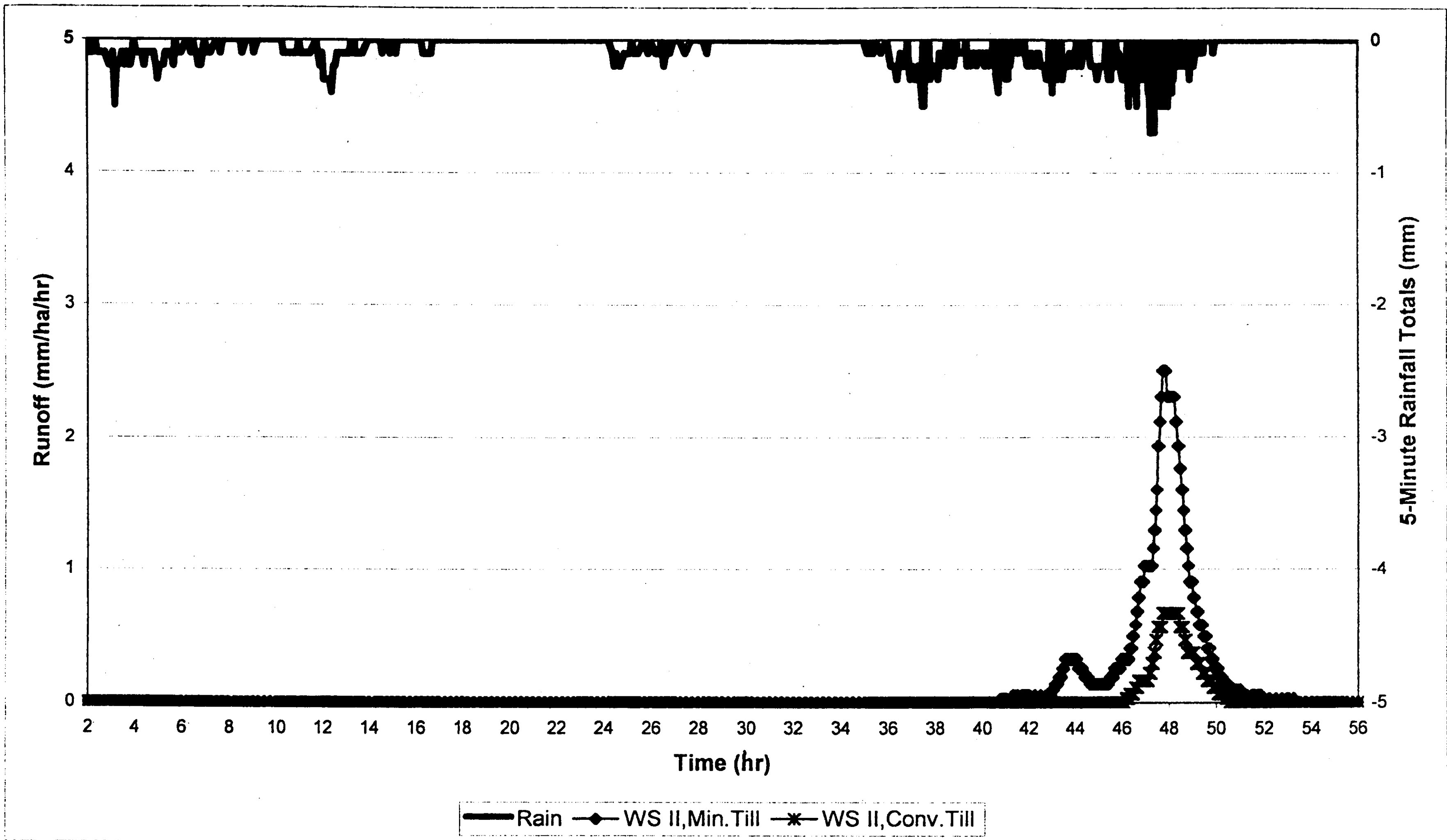

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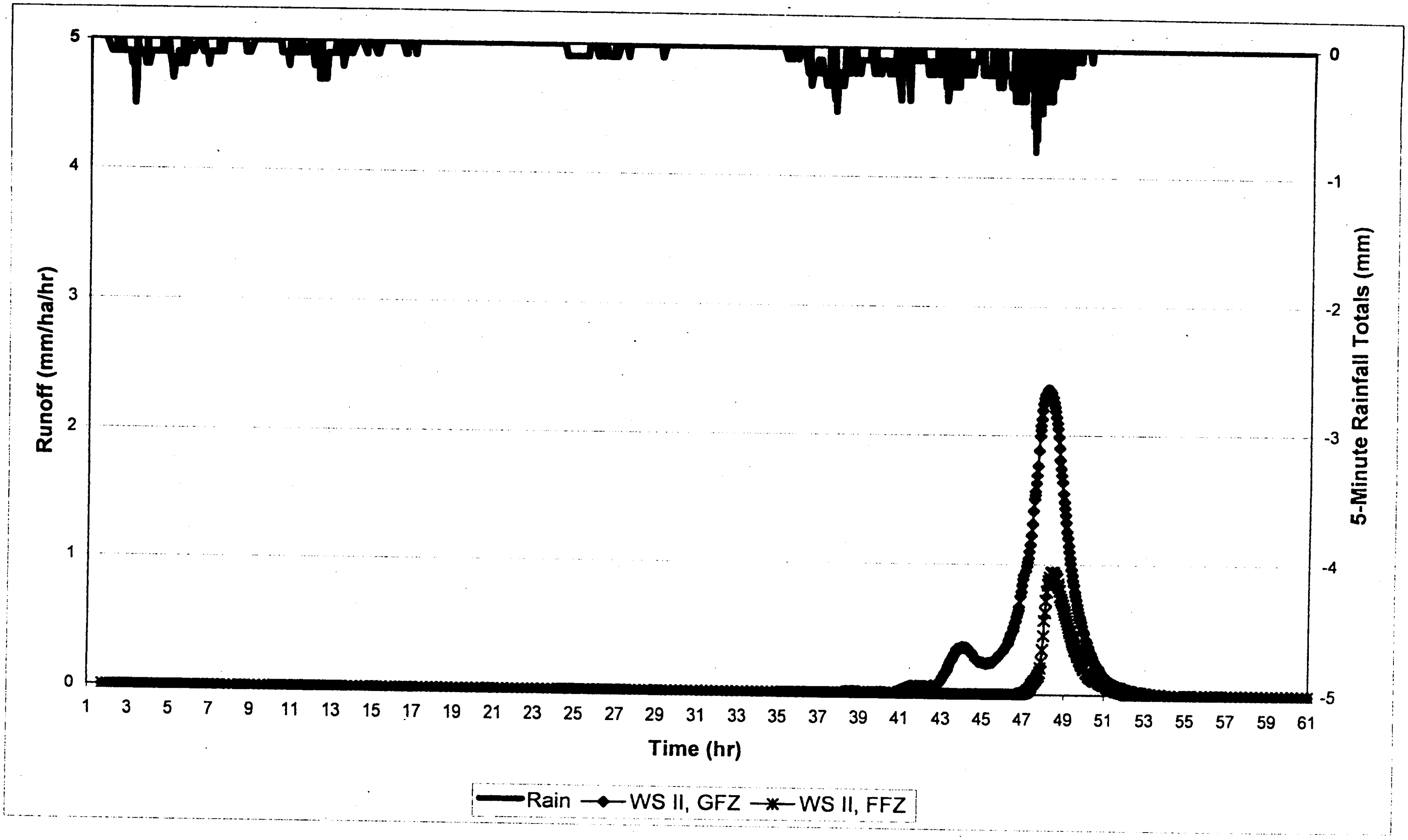

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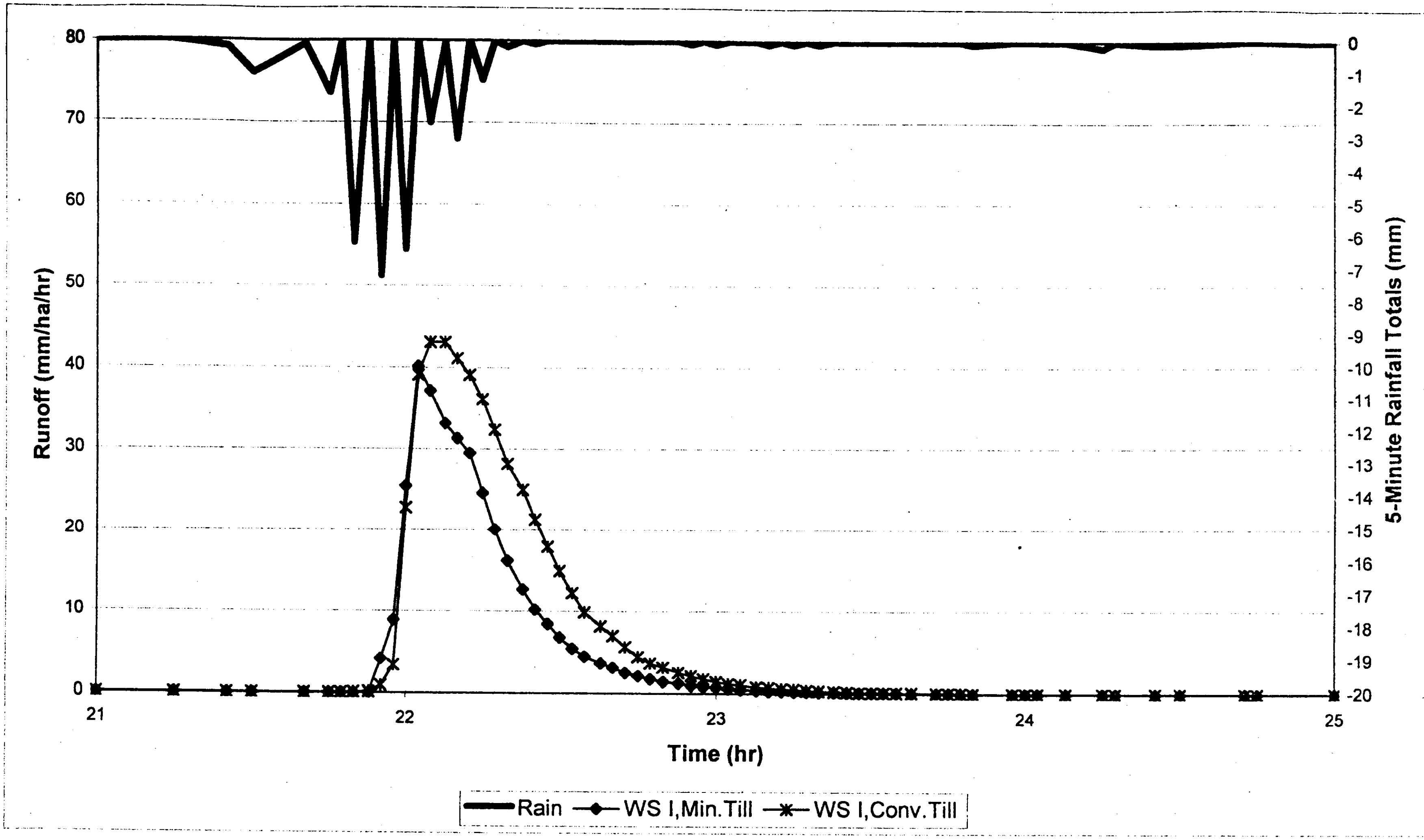

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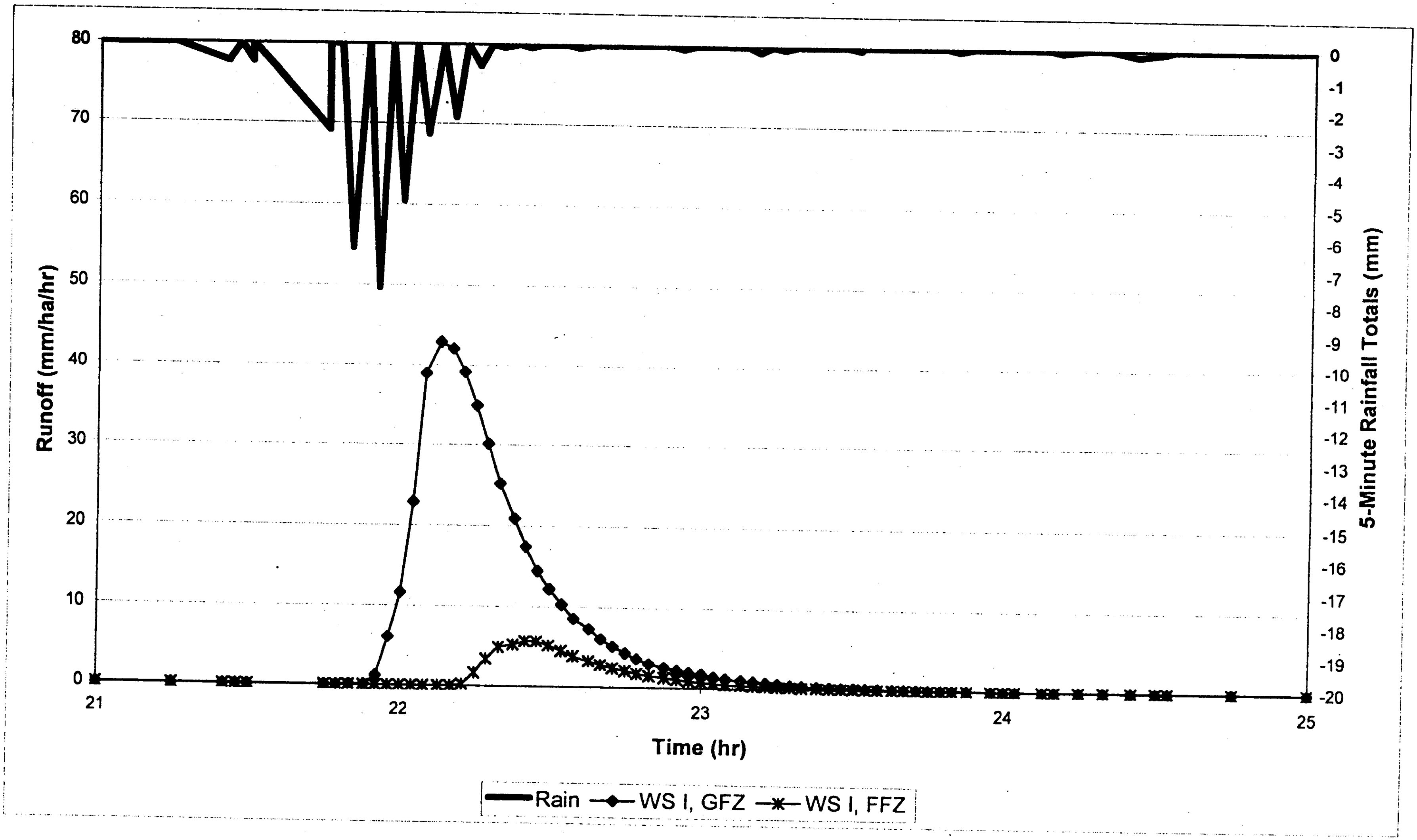
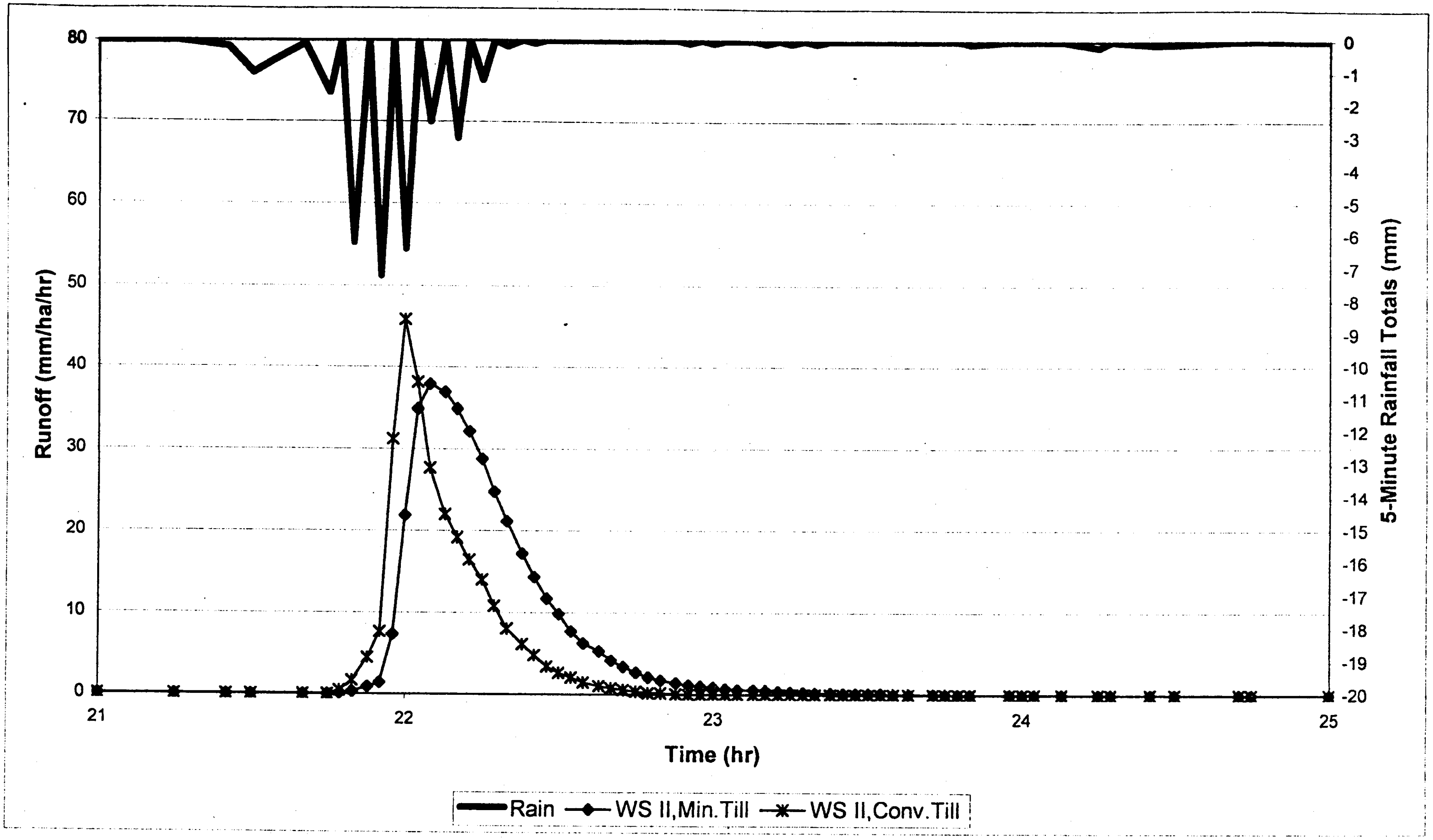
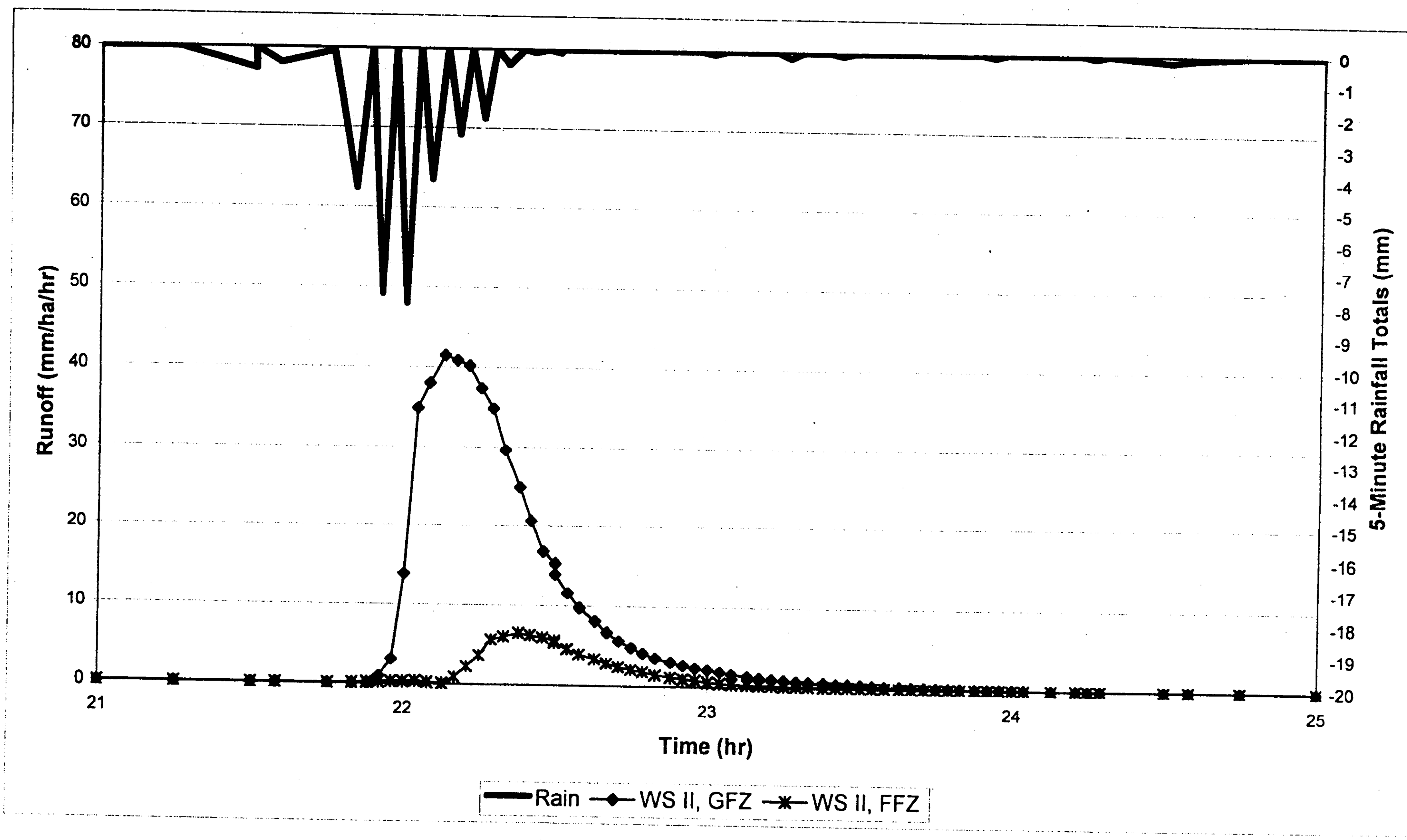


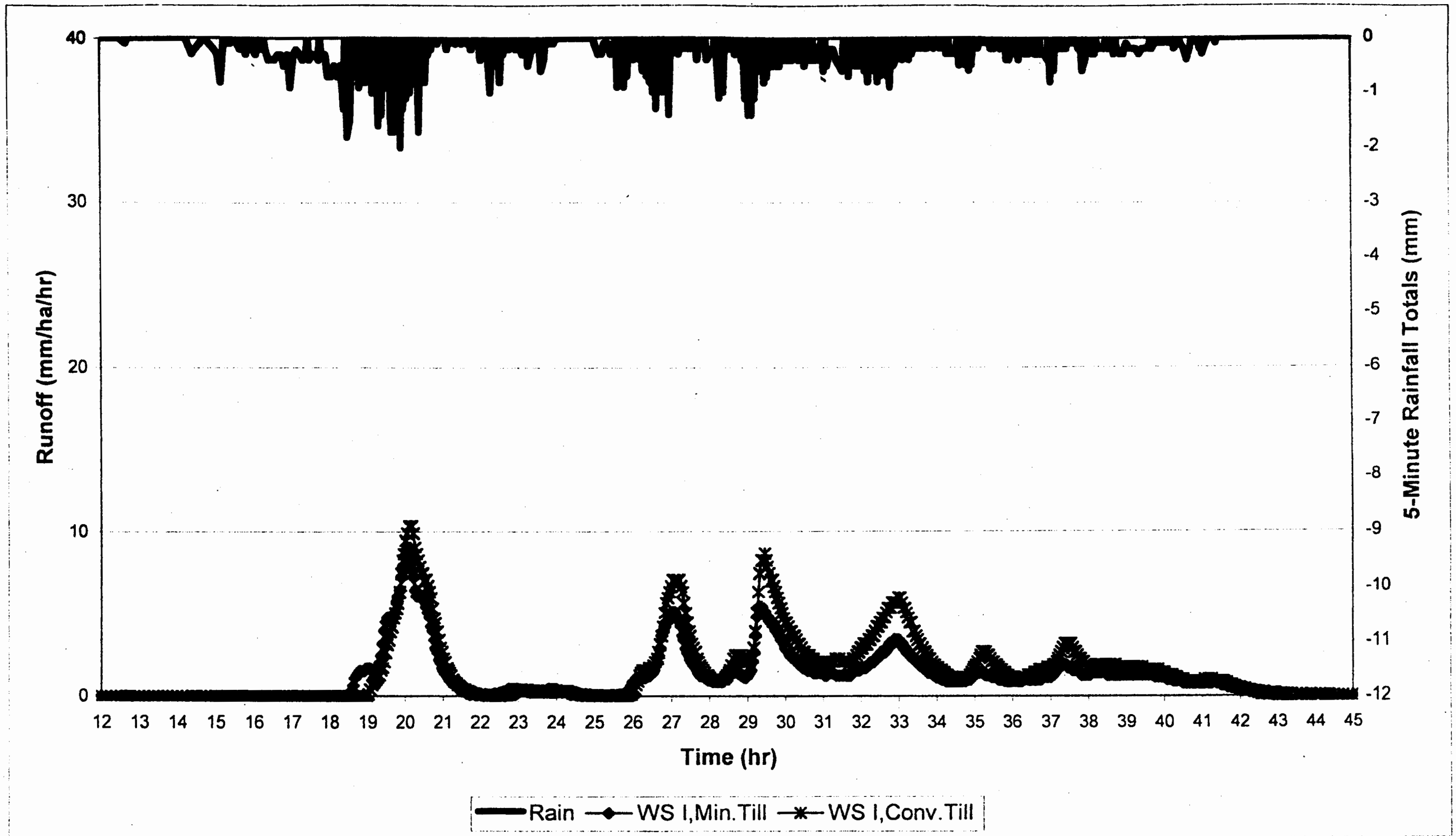
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 237, 1999.



Storm Hydrograph for Oxford Tobacco Fields, Watershed II. Julian Day 237, 1999.



Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 237, 1999.



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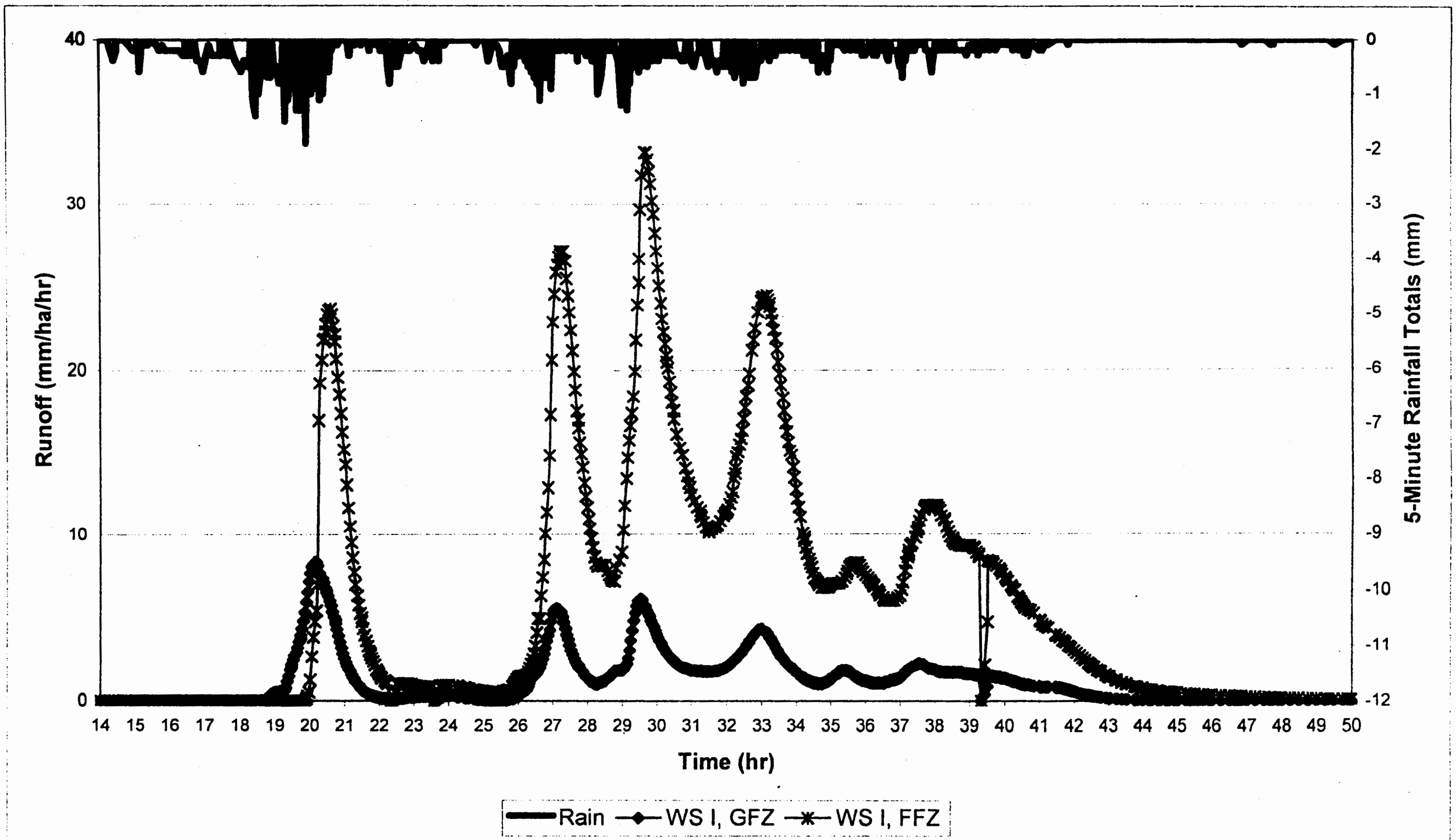

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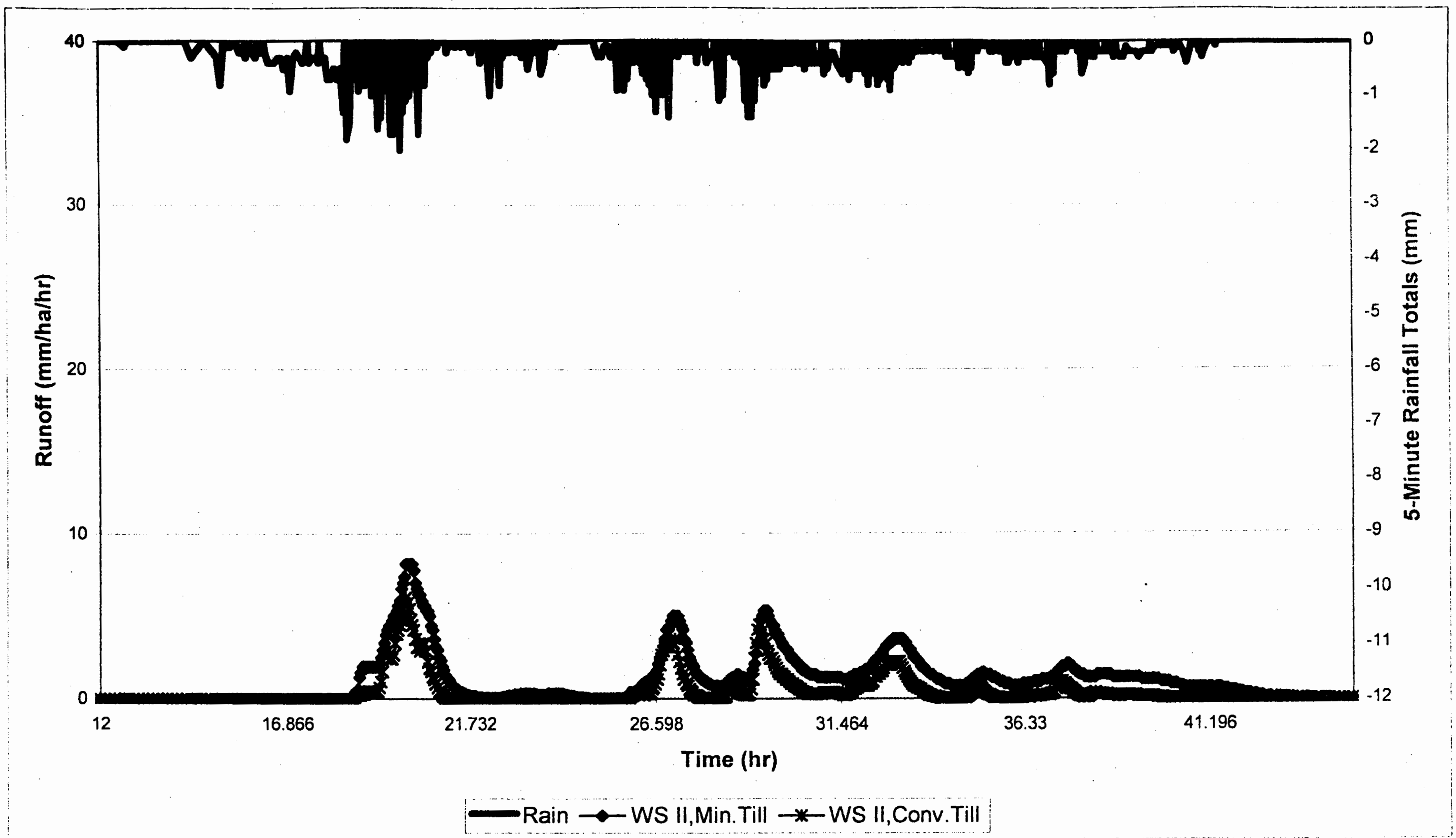
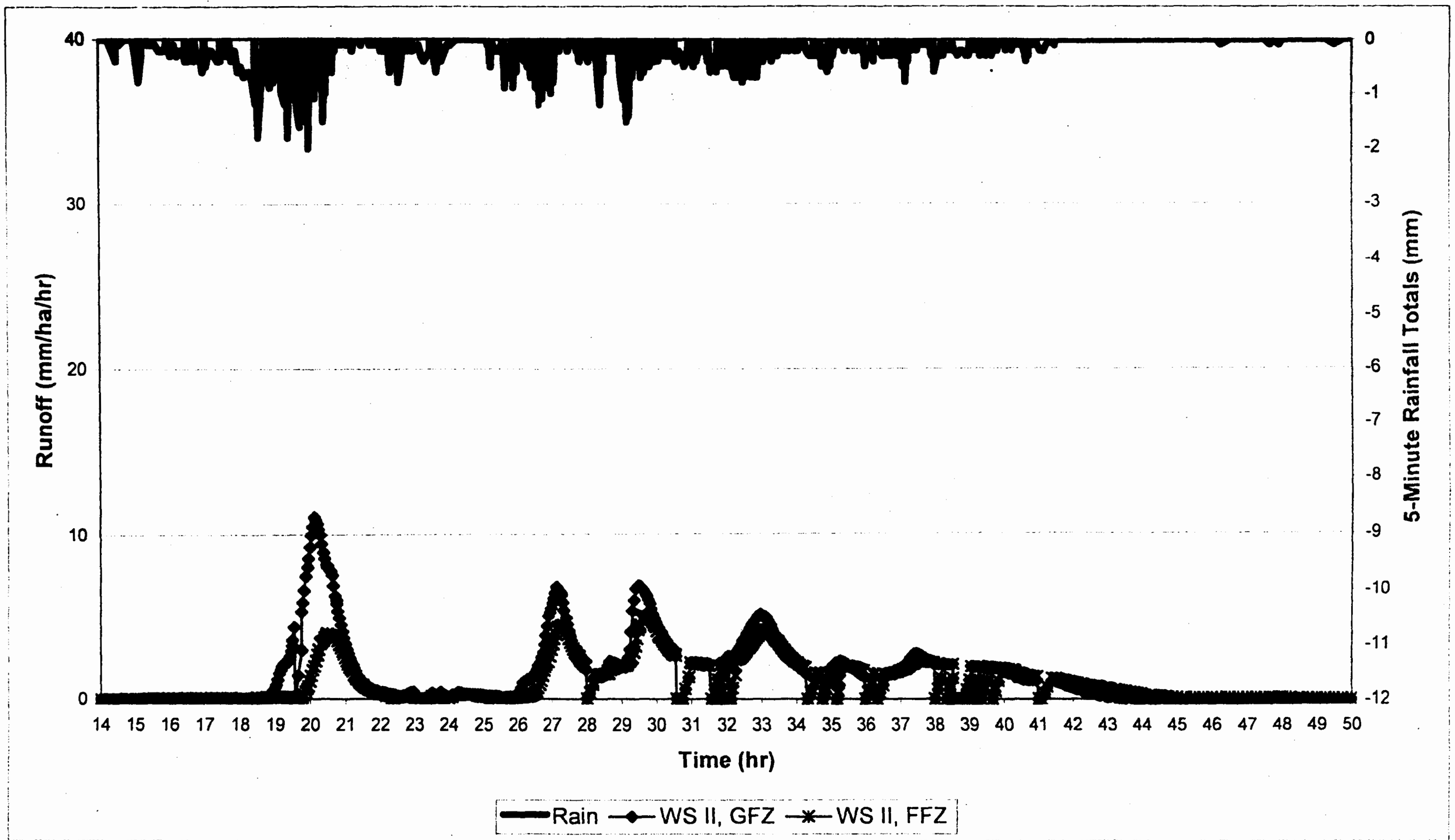


Storm Hydrograph for Oxford Tobacco Fields, Watershed II. Julian Day 247, 1999.



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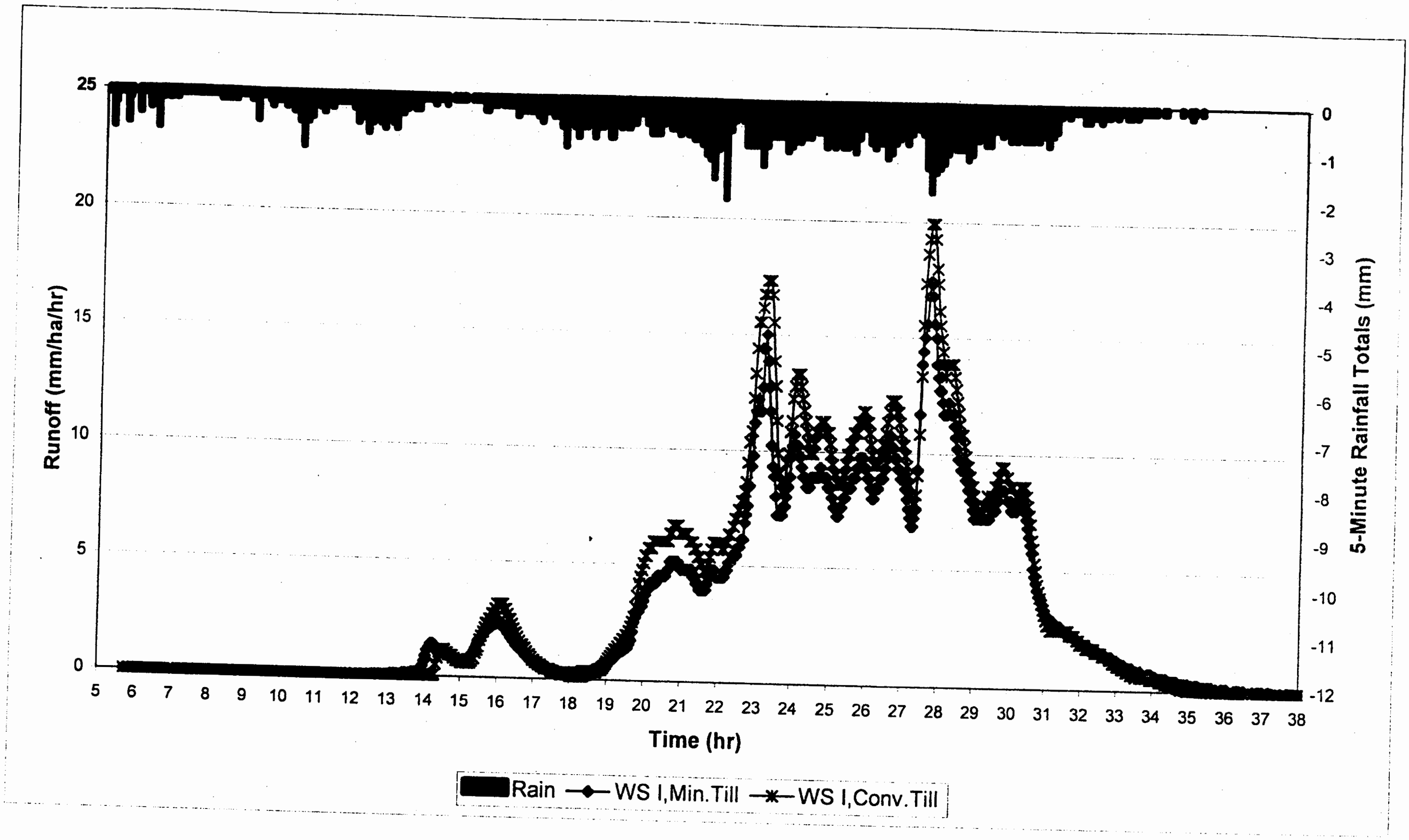

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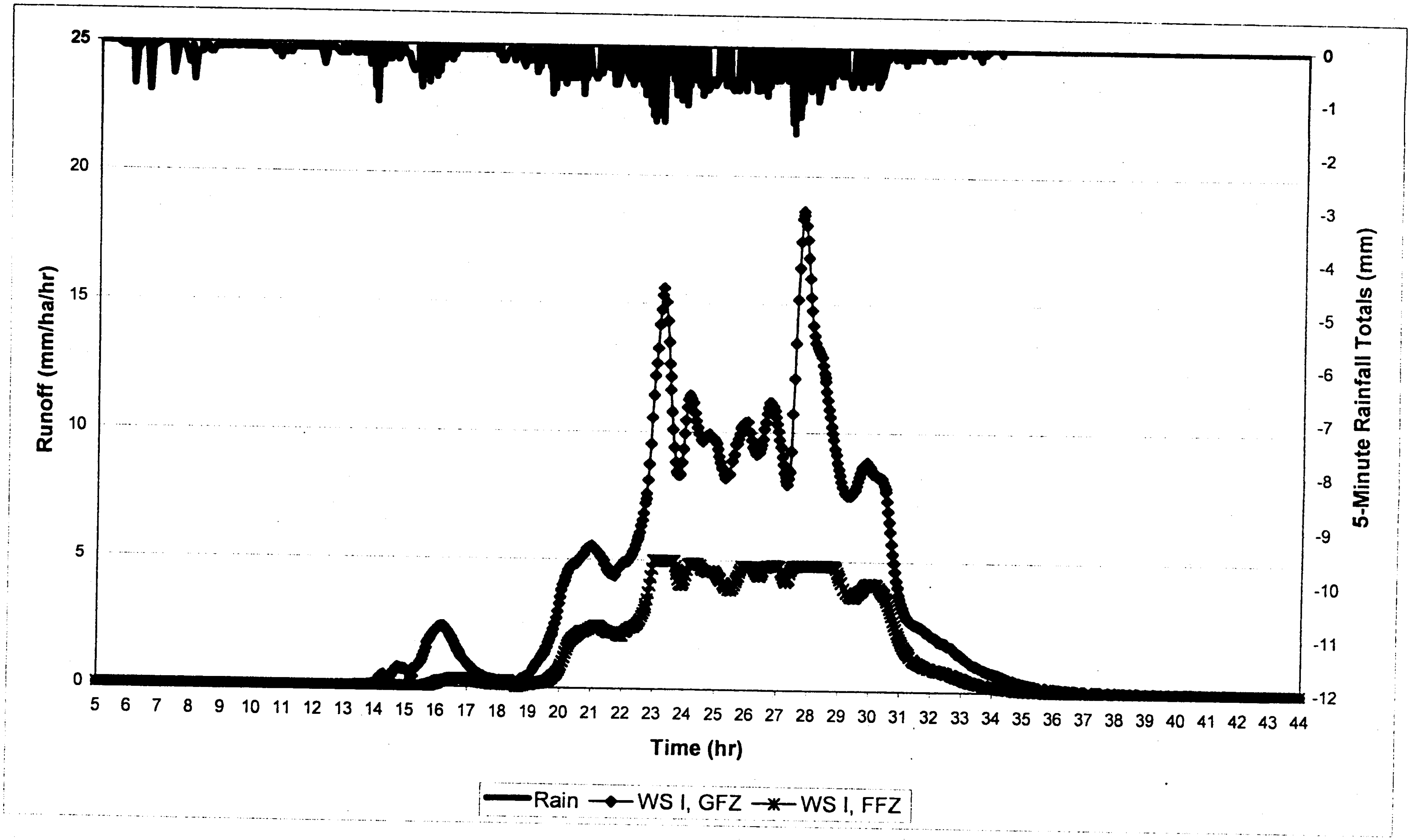

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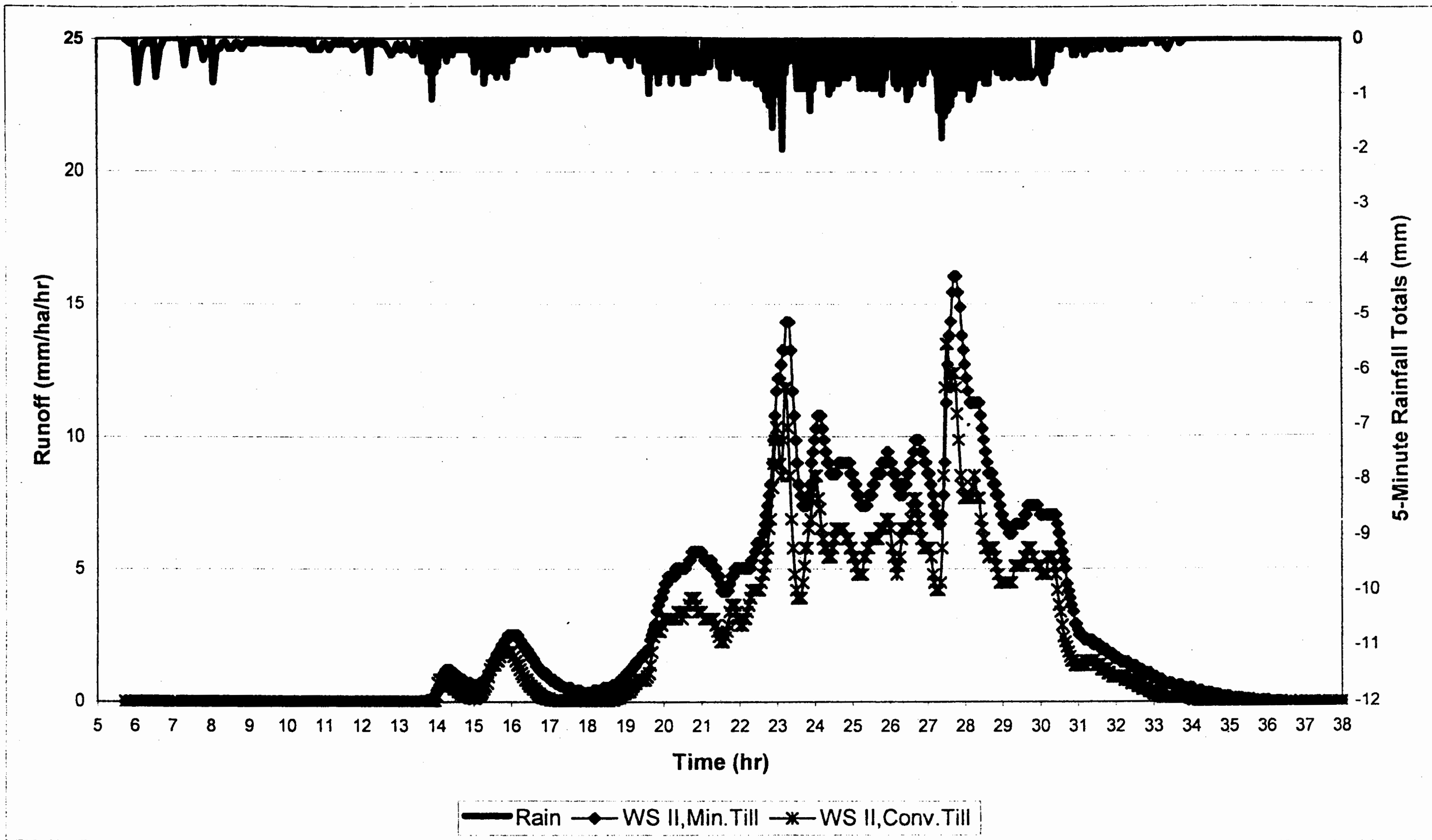

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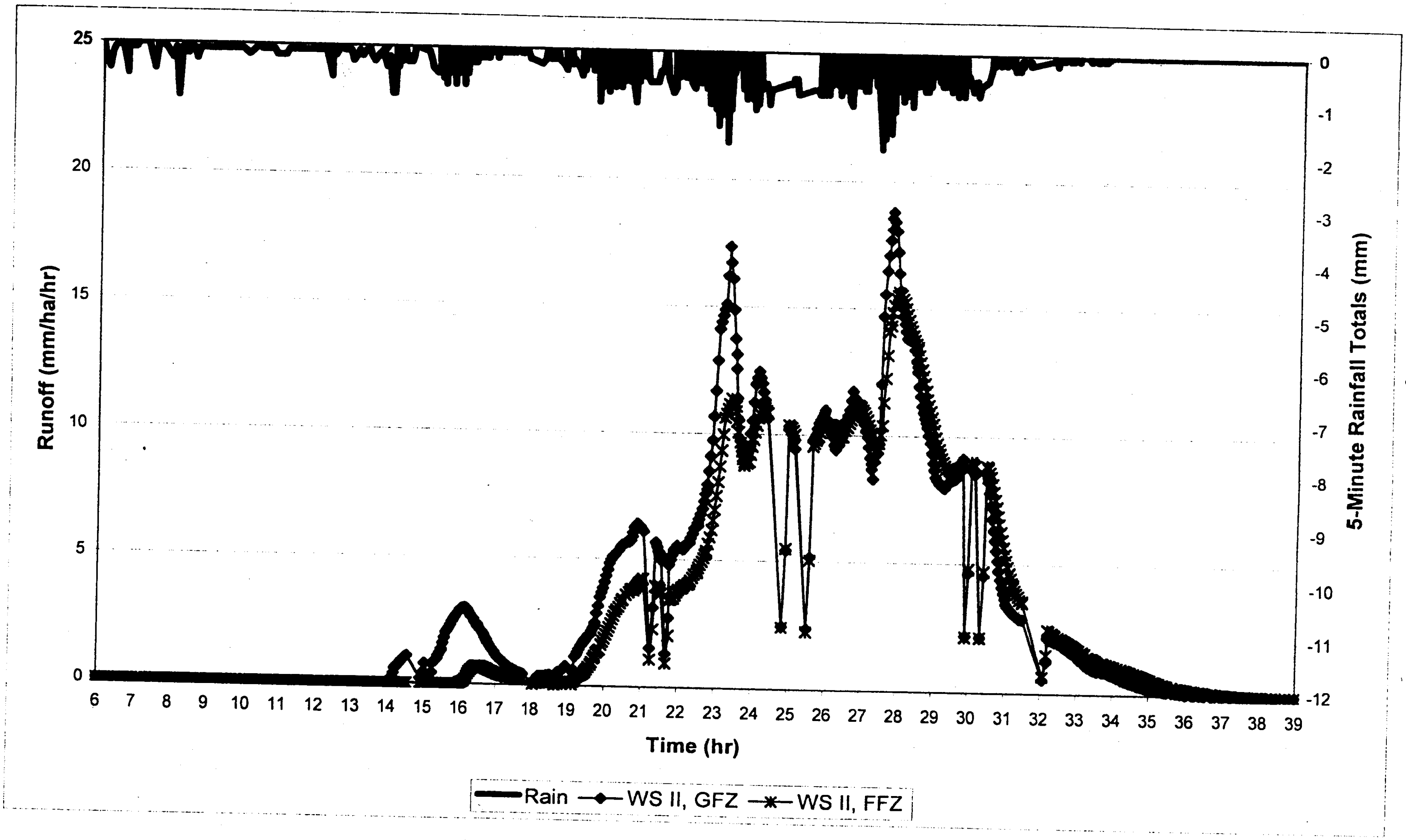
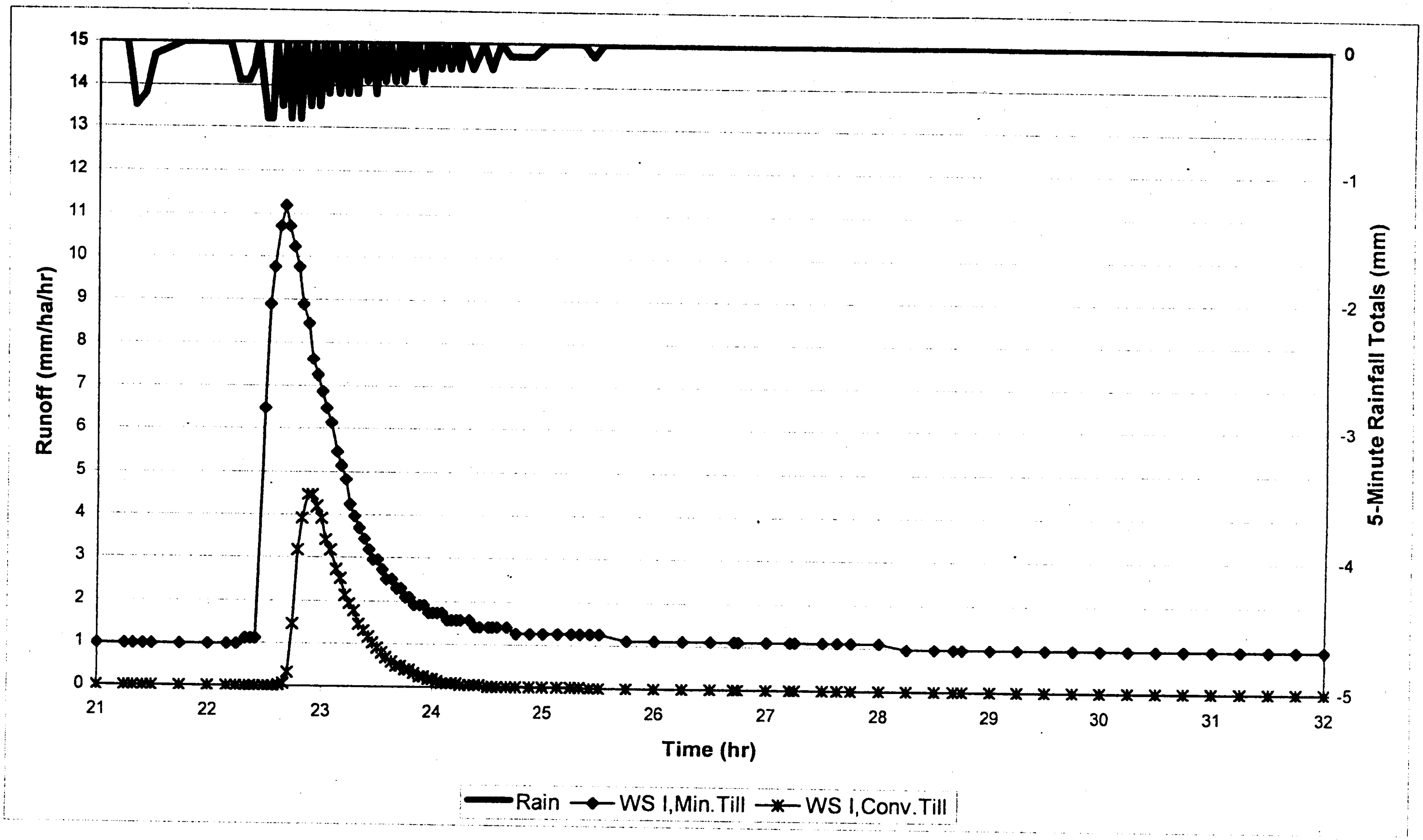


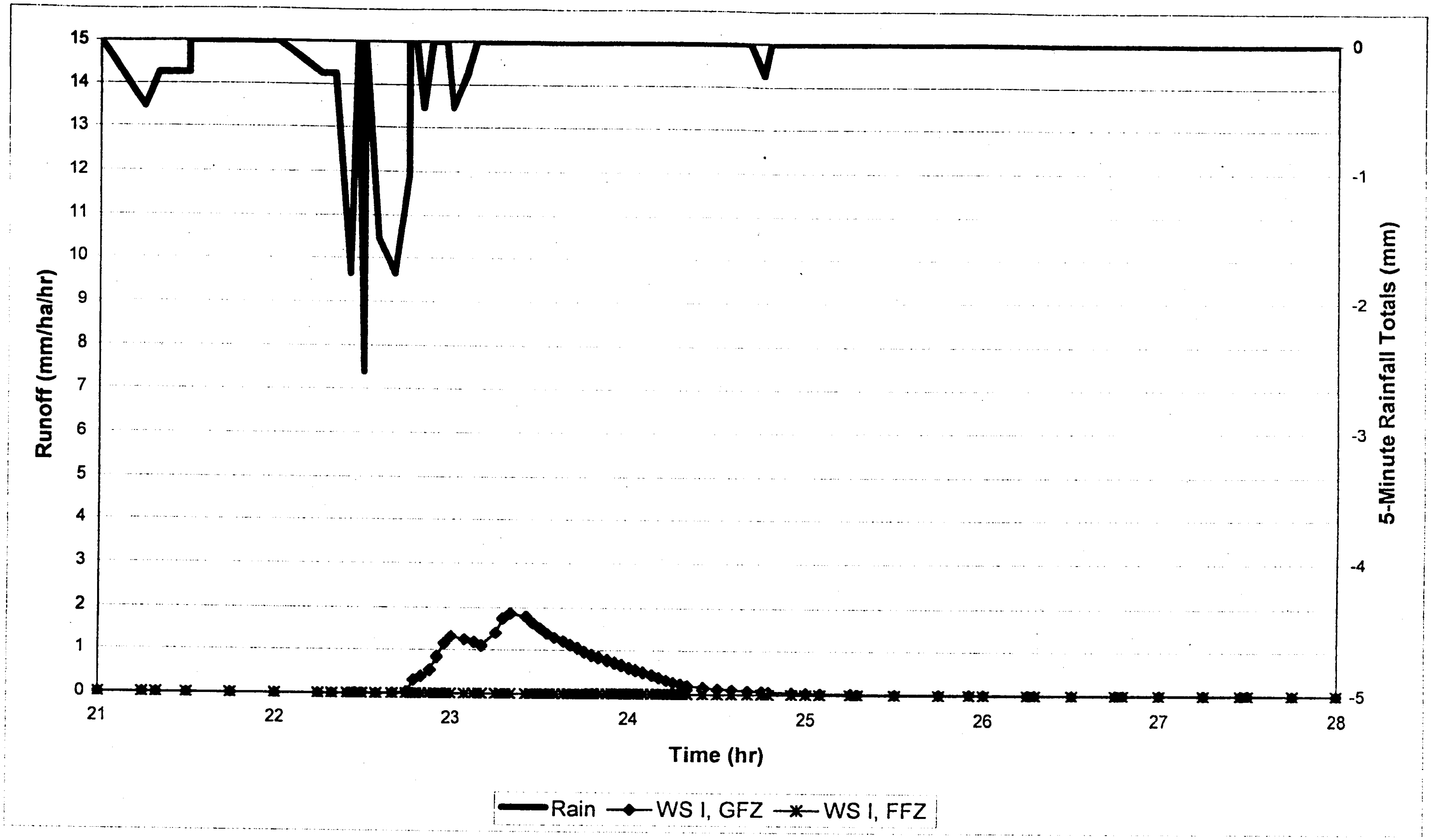
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 258, 1999.

APPENDIX 3

RAINFALL EVENT HYDROGRAPHS FOR 2000



Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 148, 2000.



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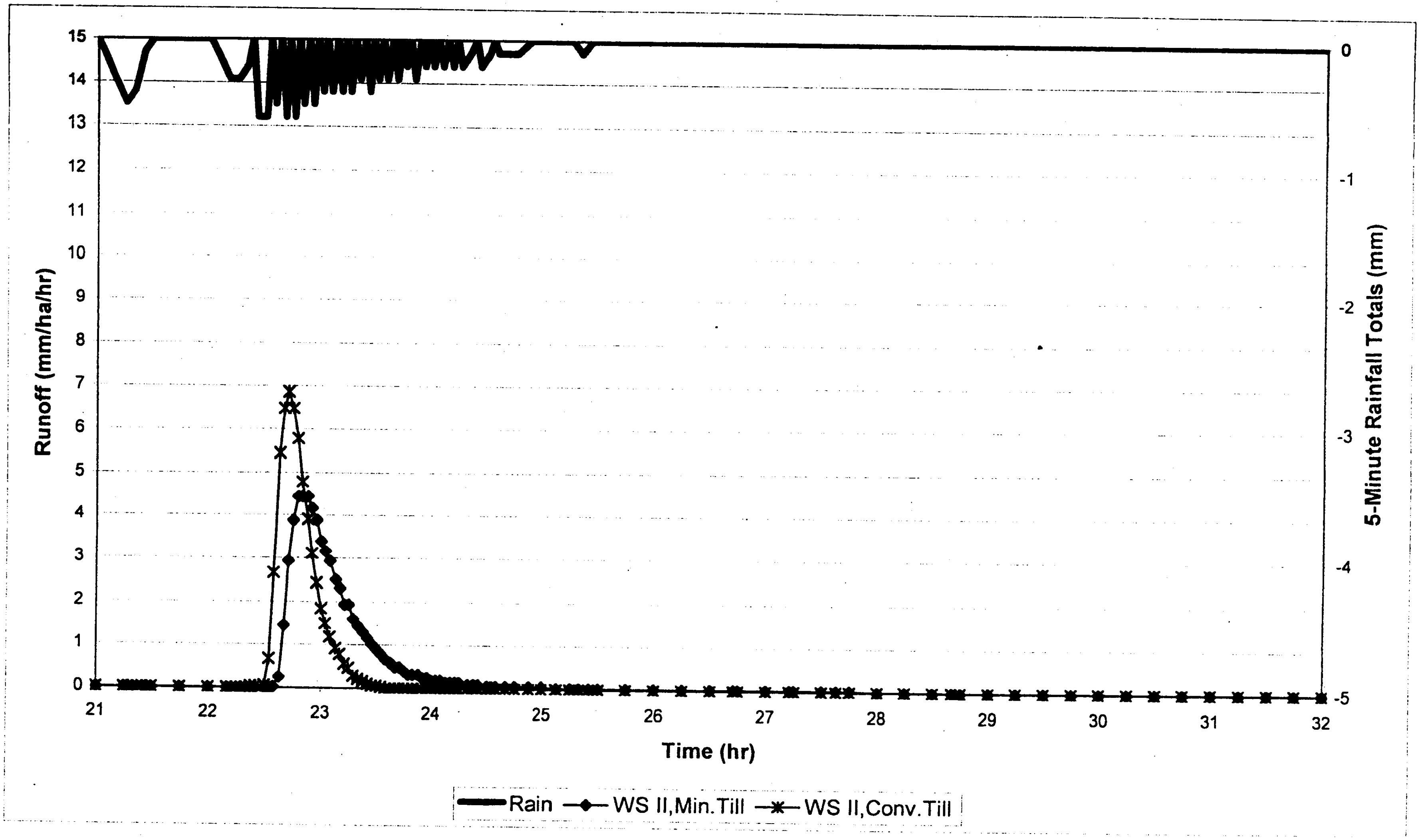

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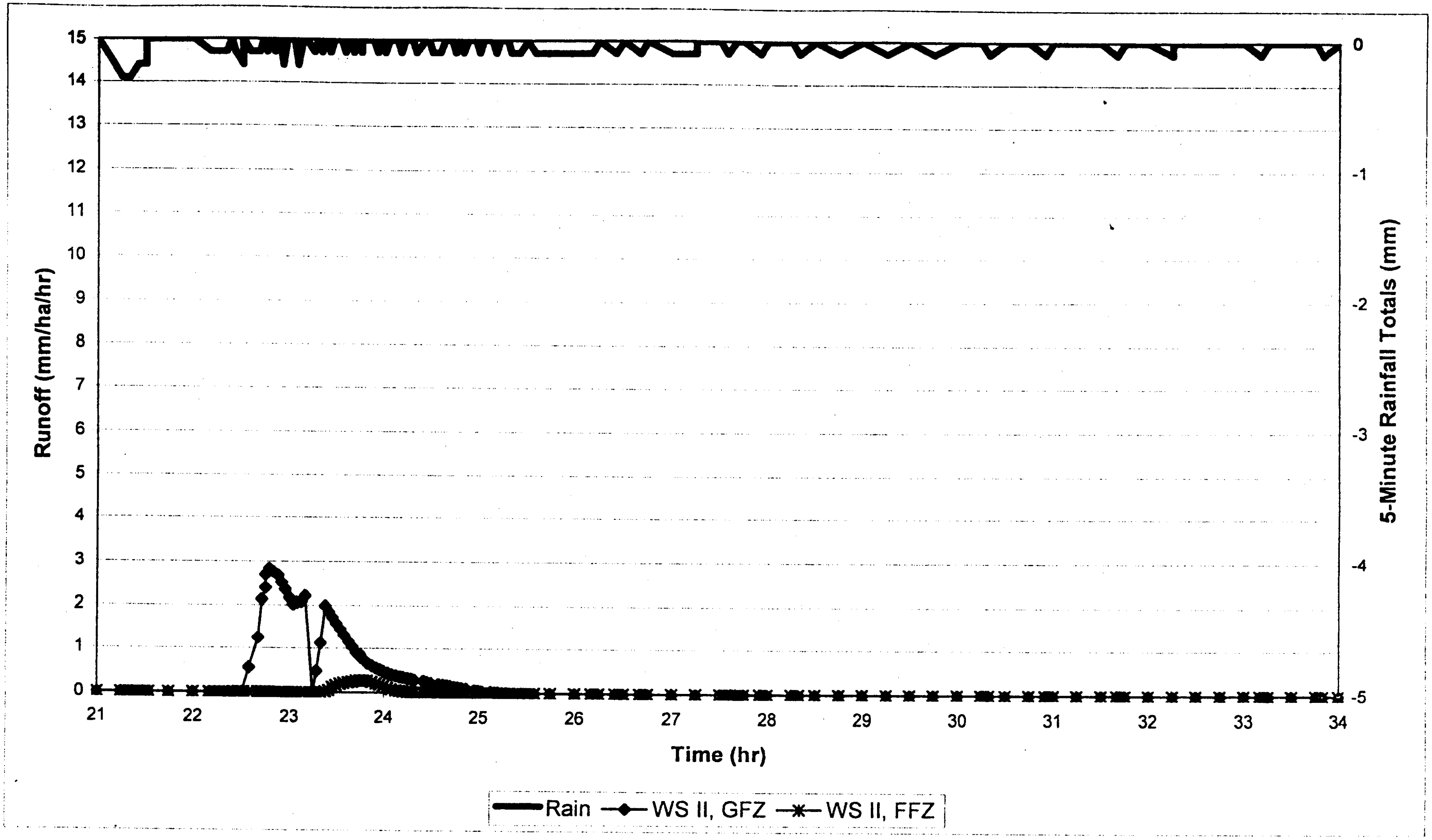

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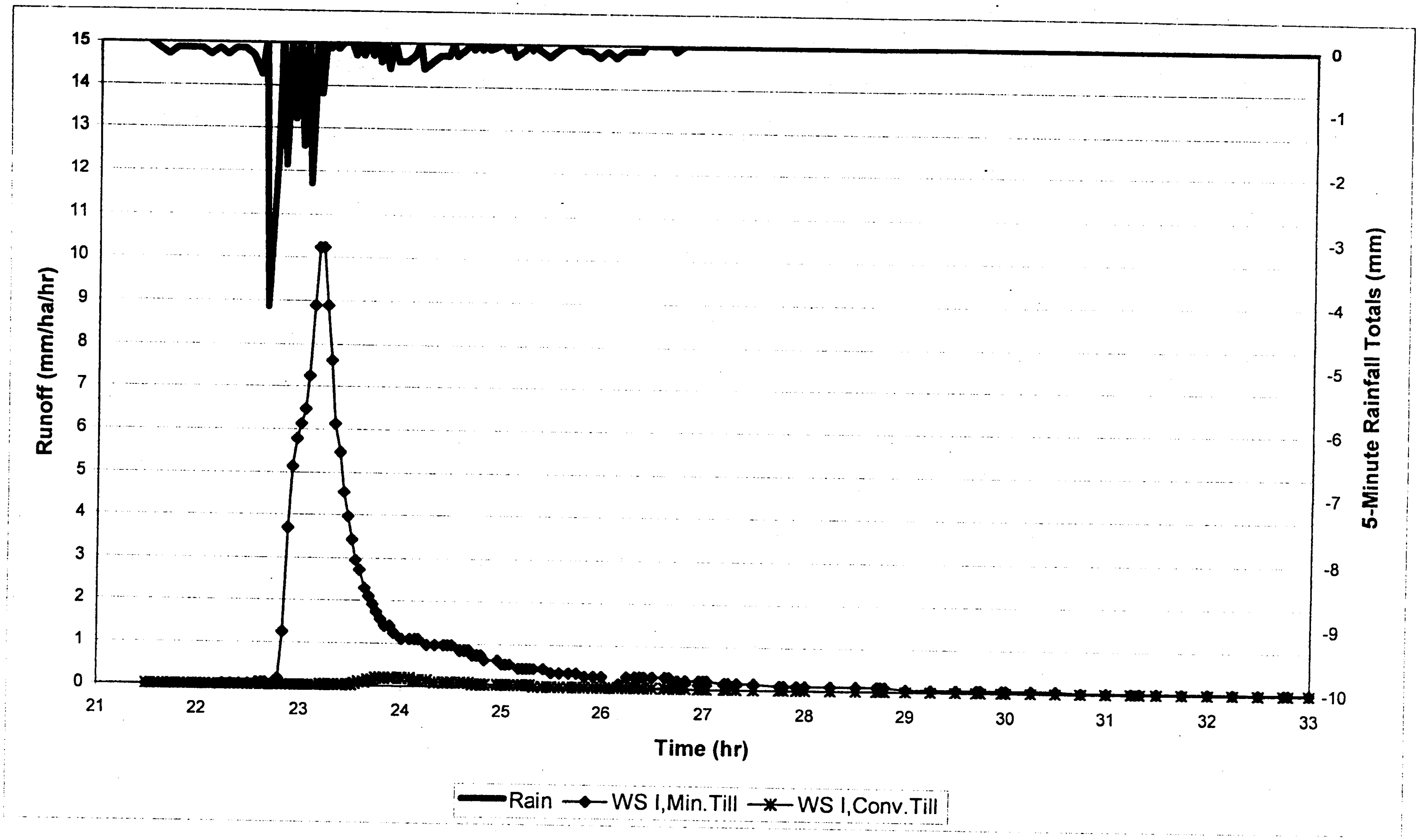
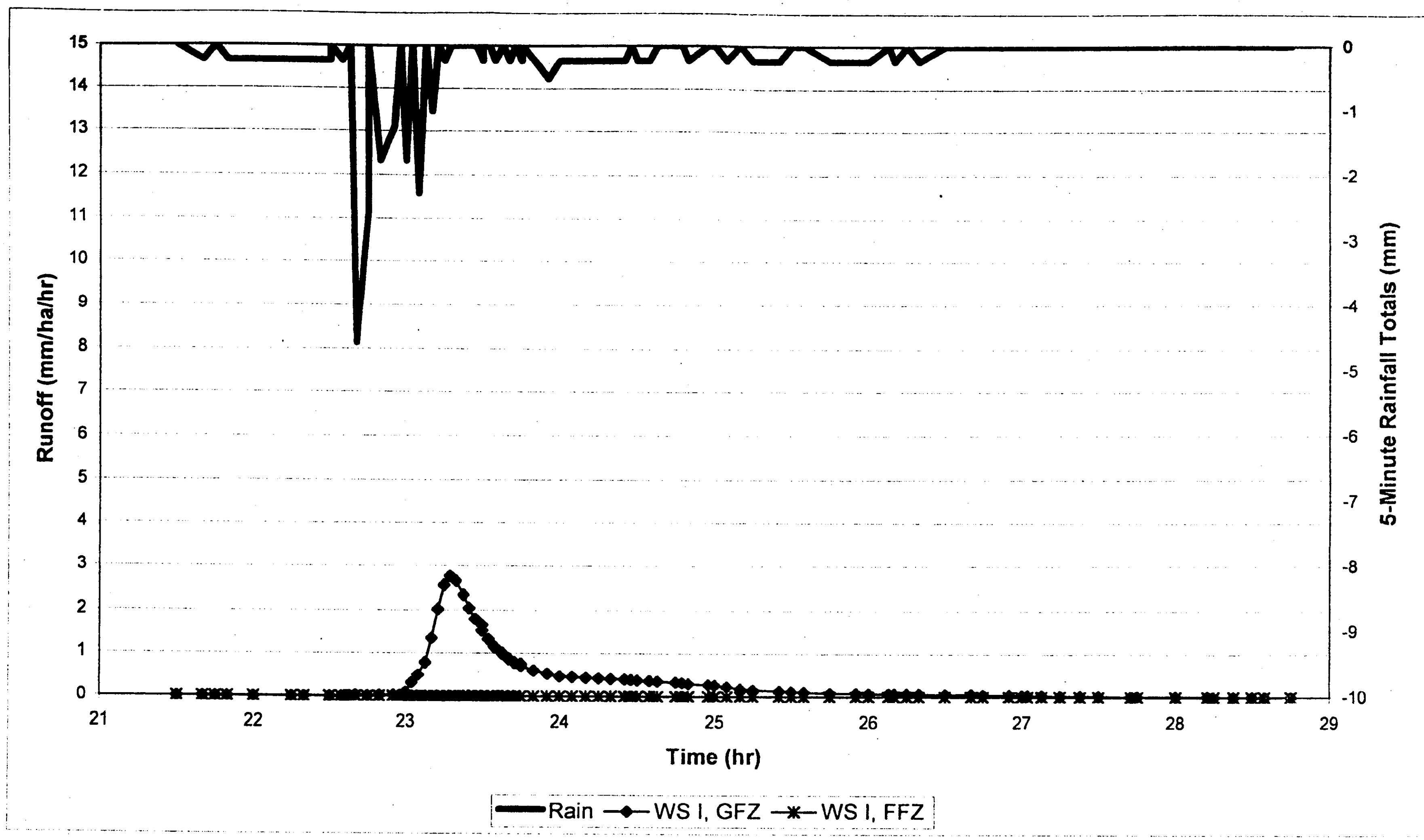


Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 167, 2000.



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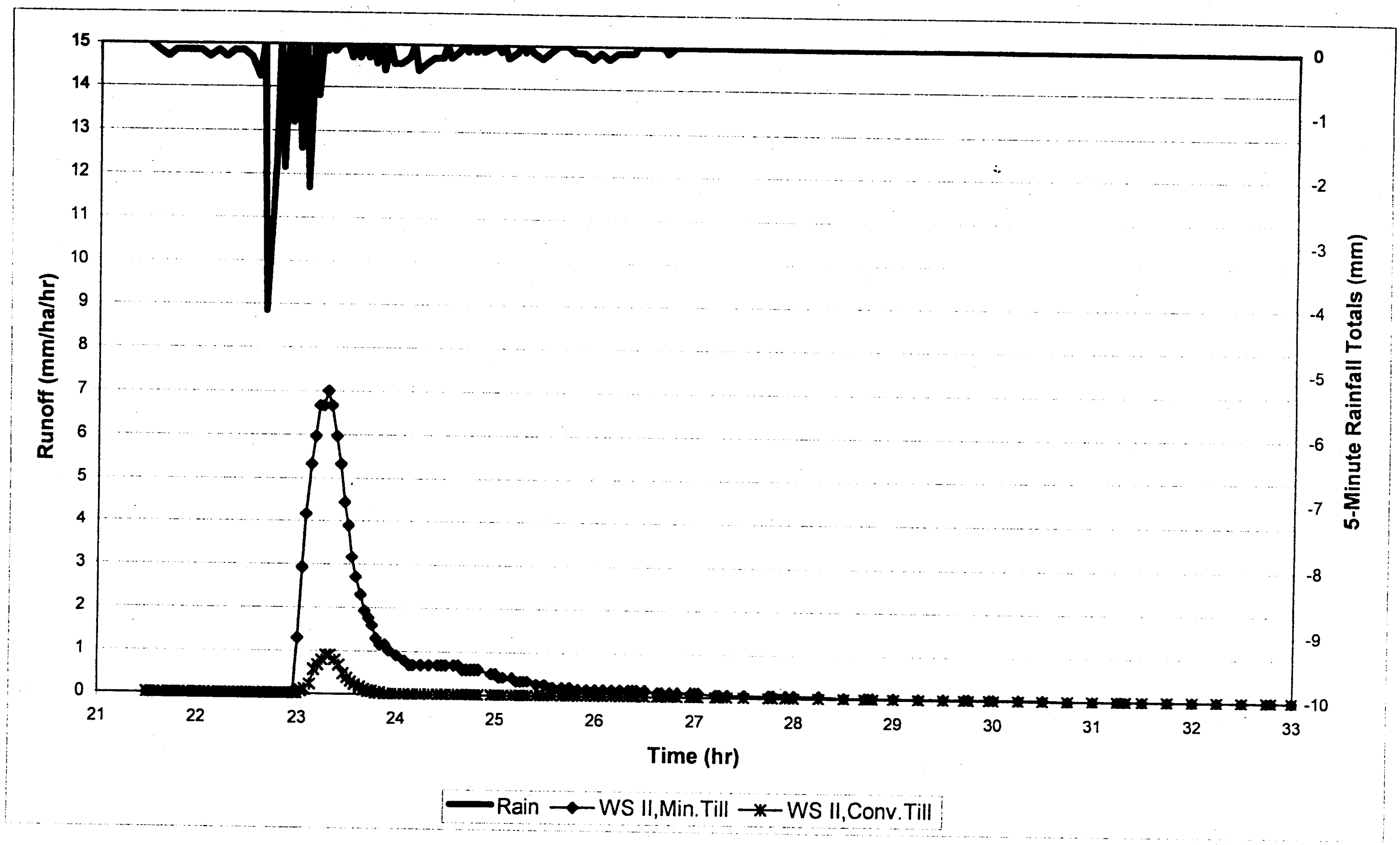

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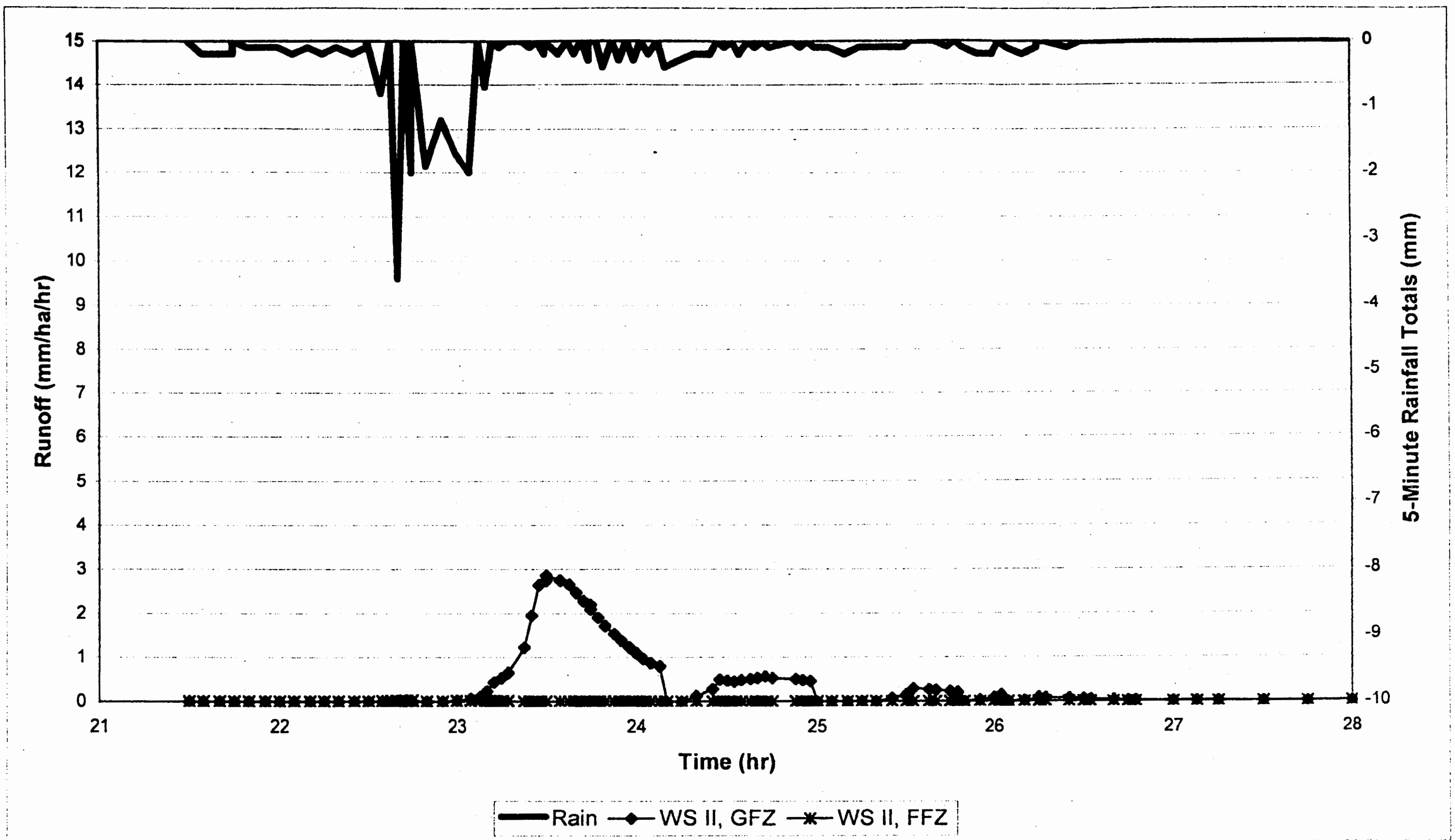

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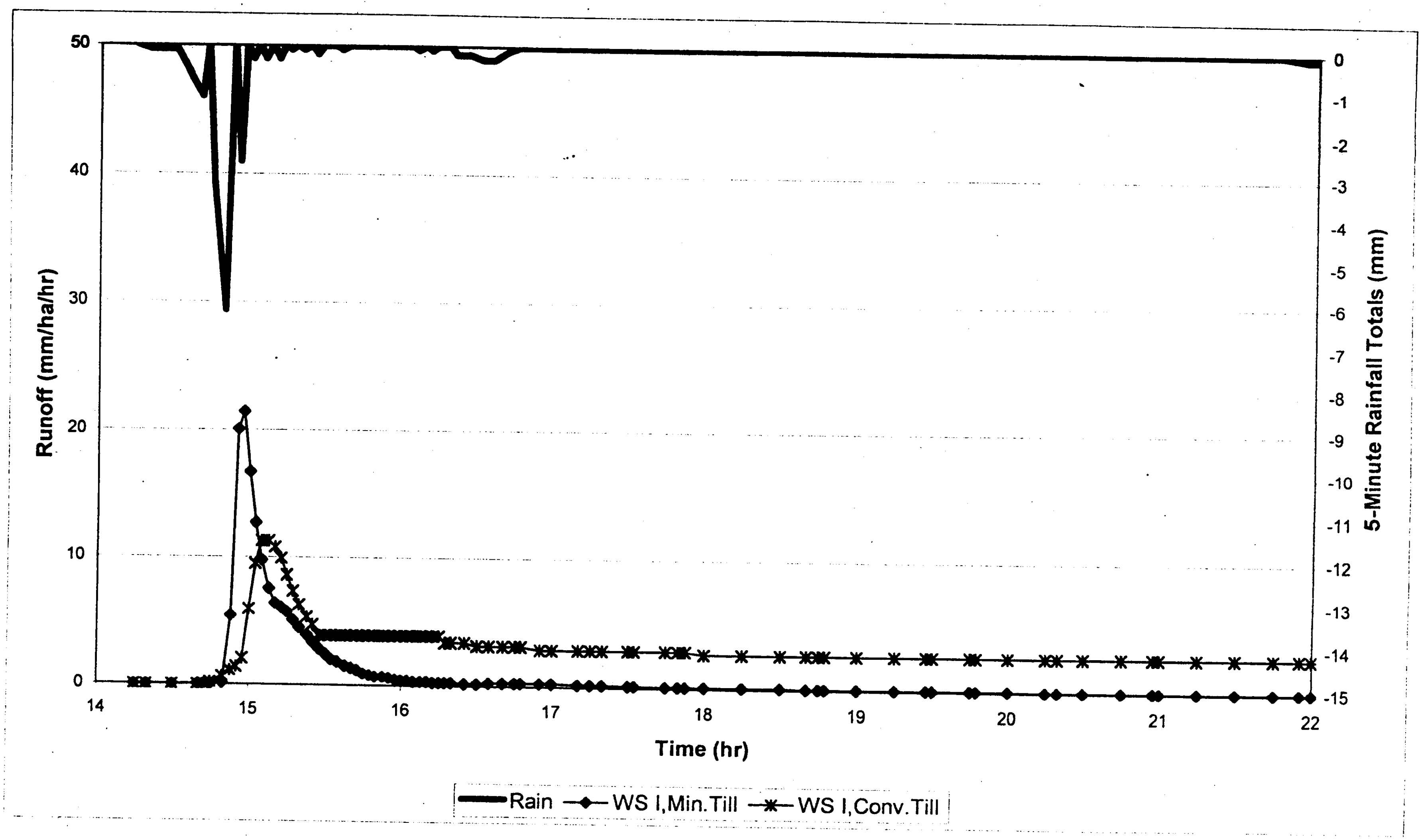

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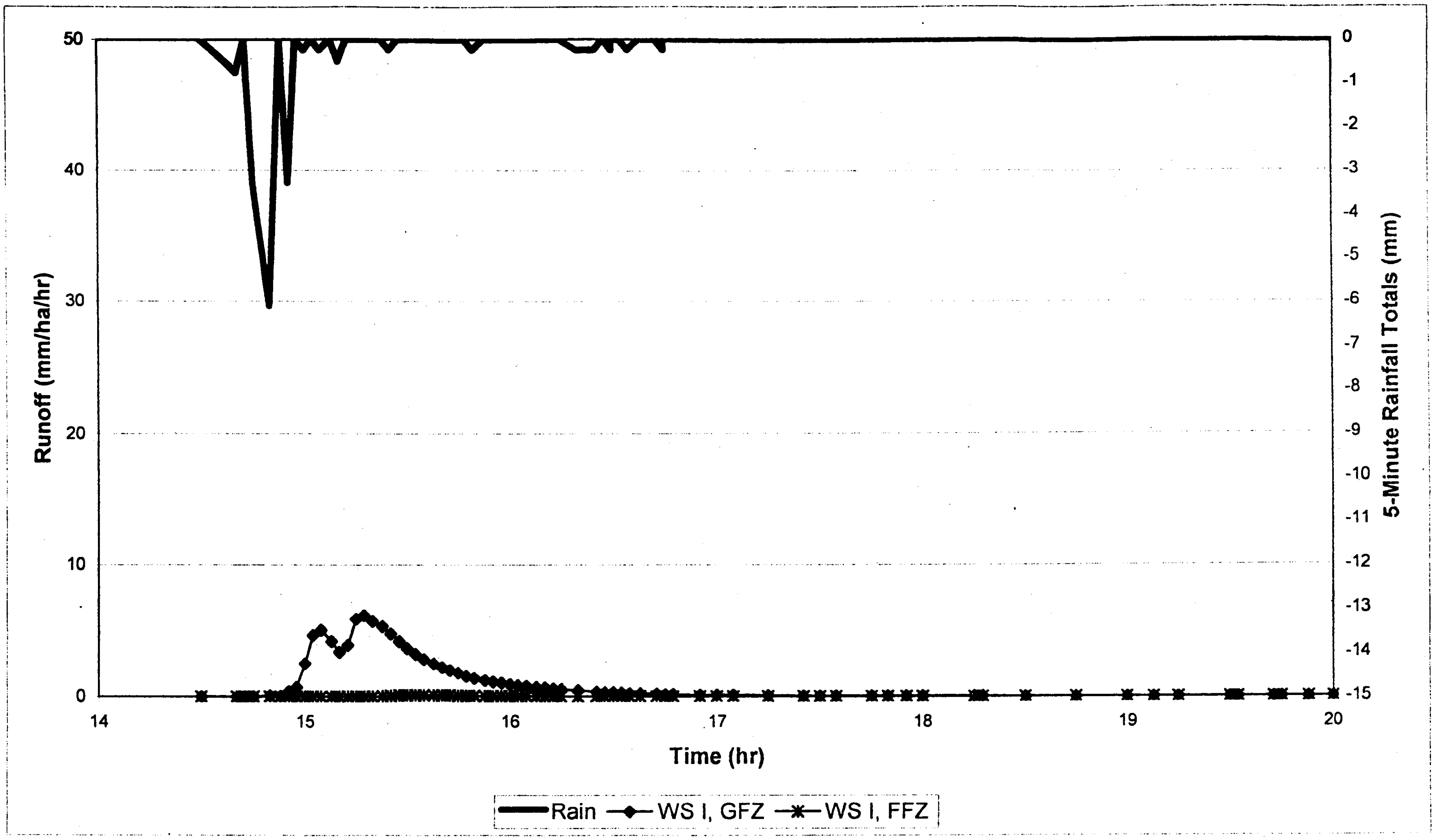

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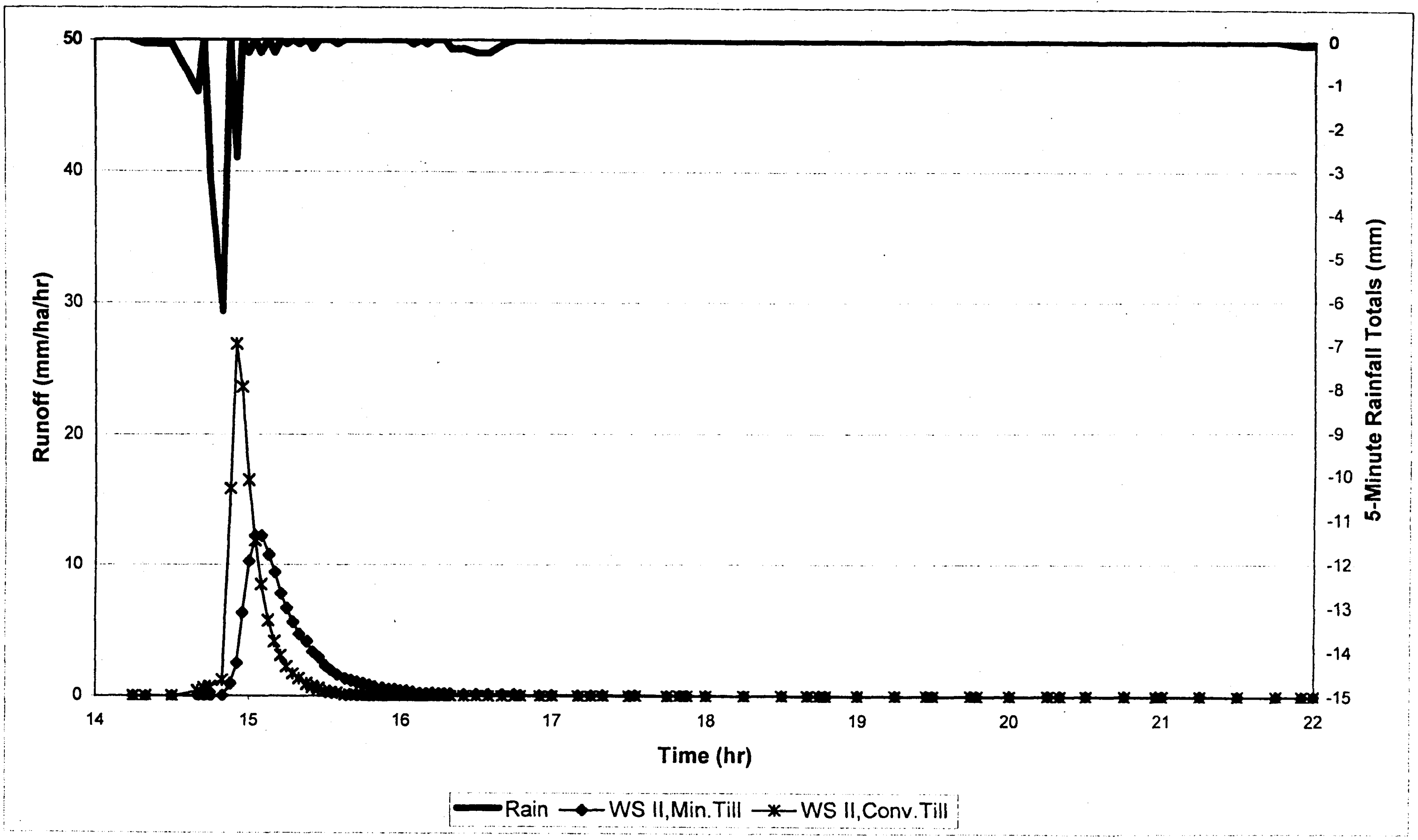

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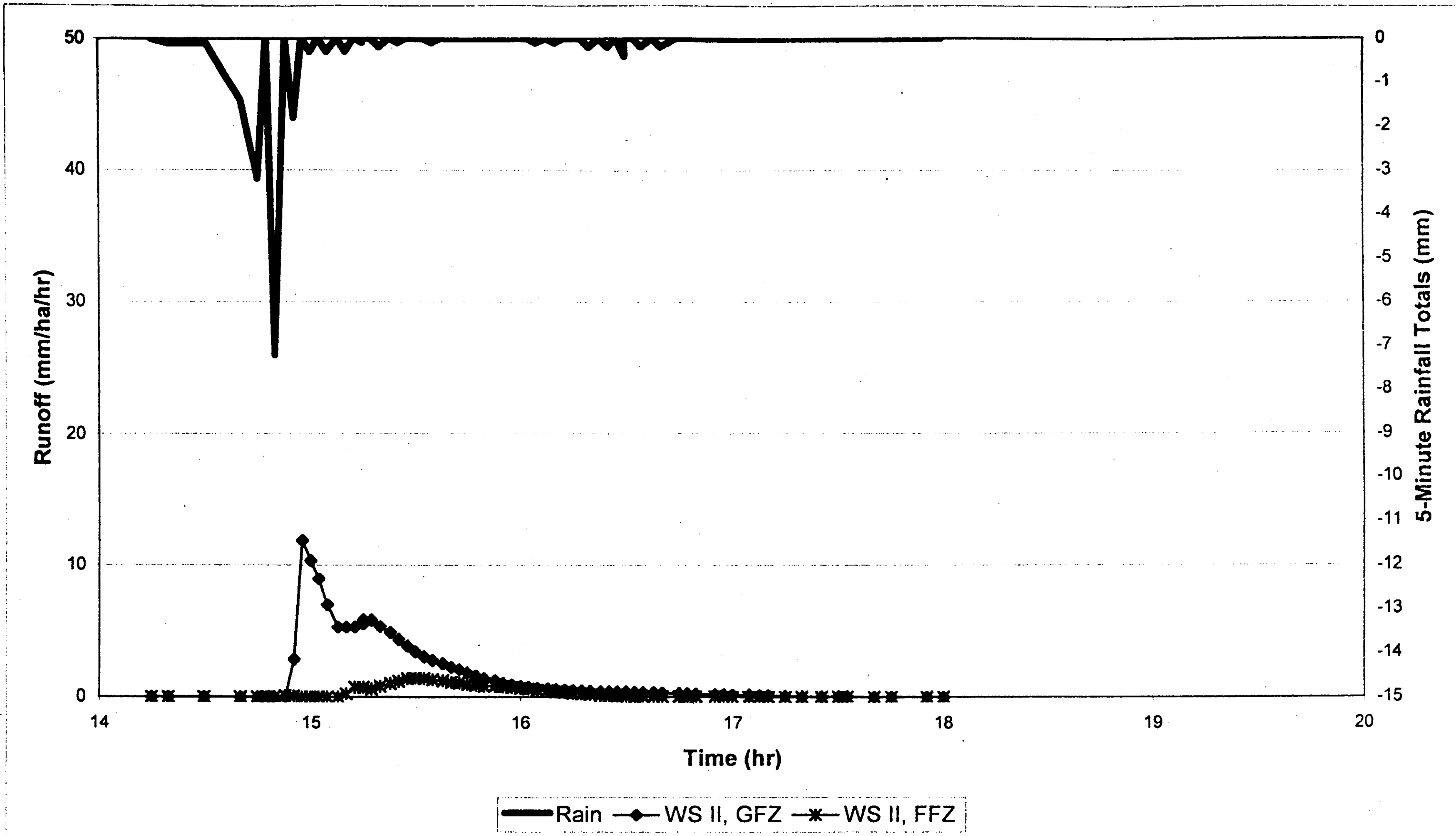

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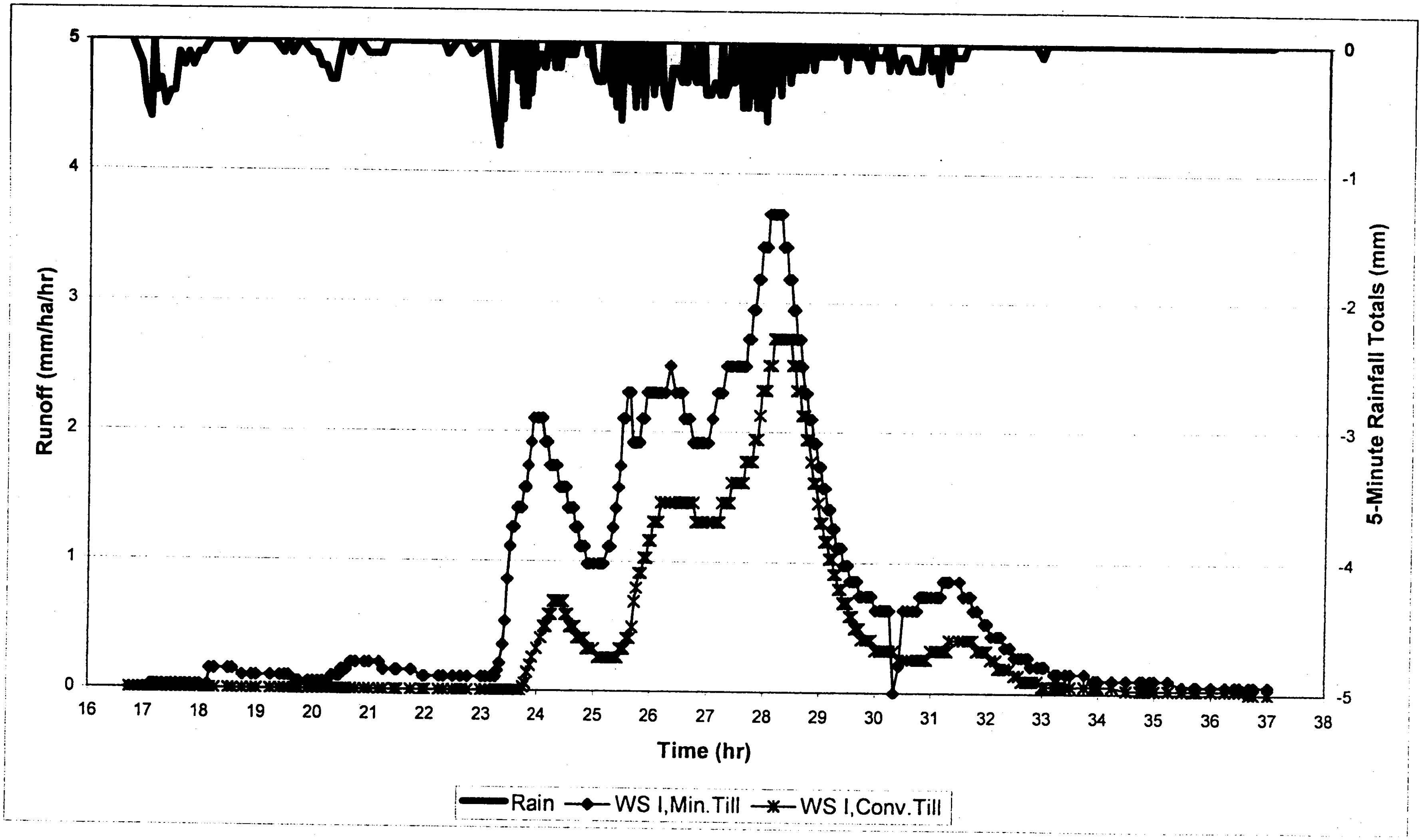
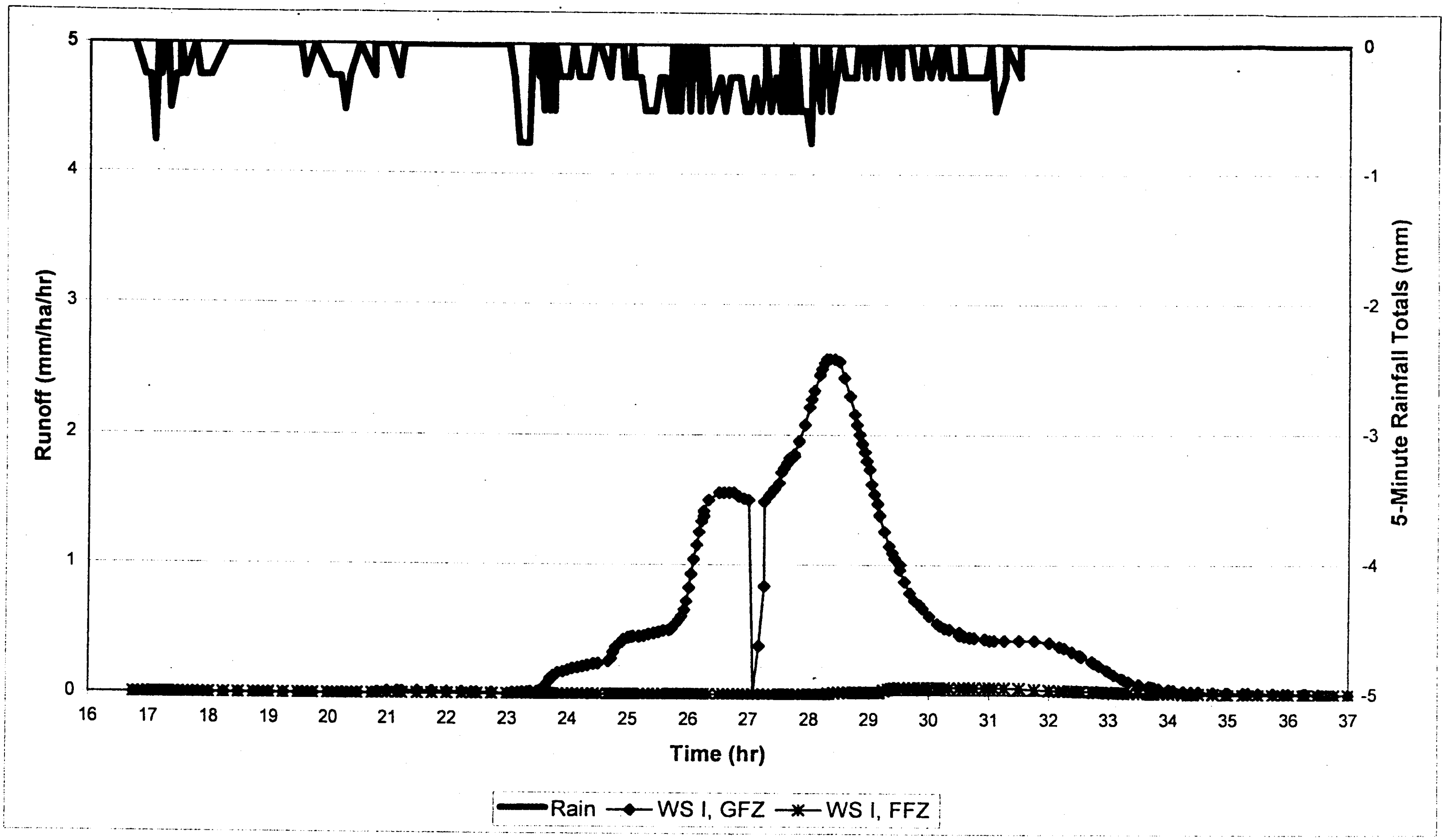


Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 205, 2000.



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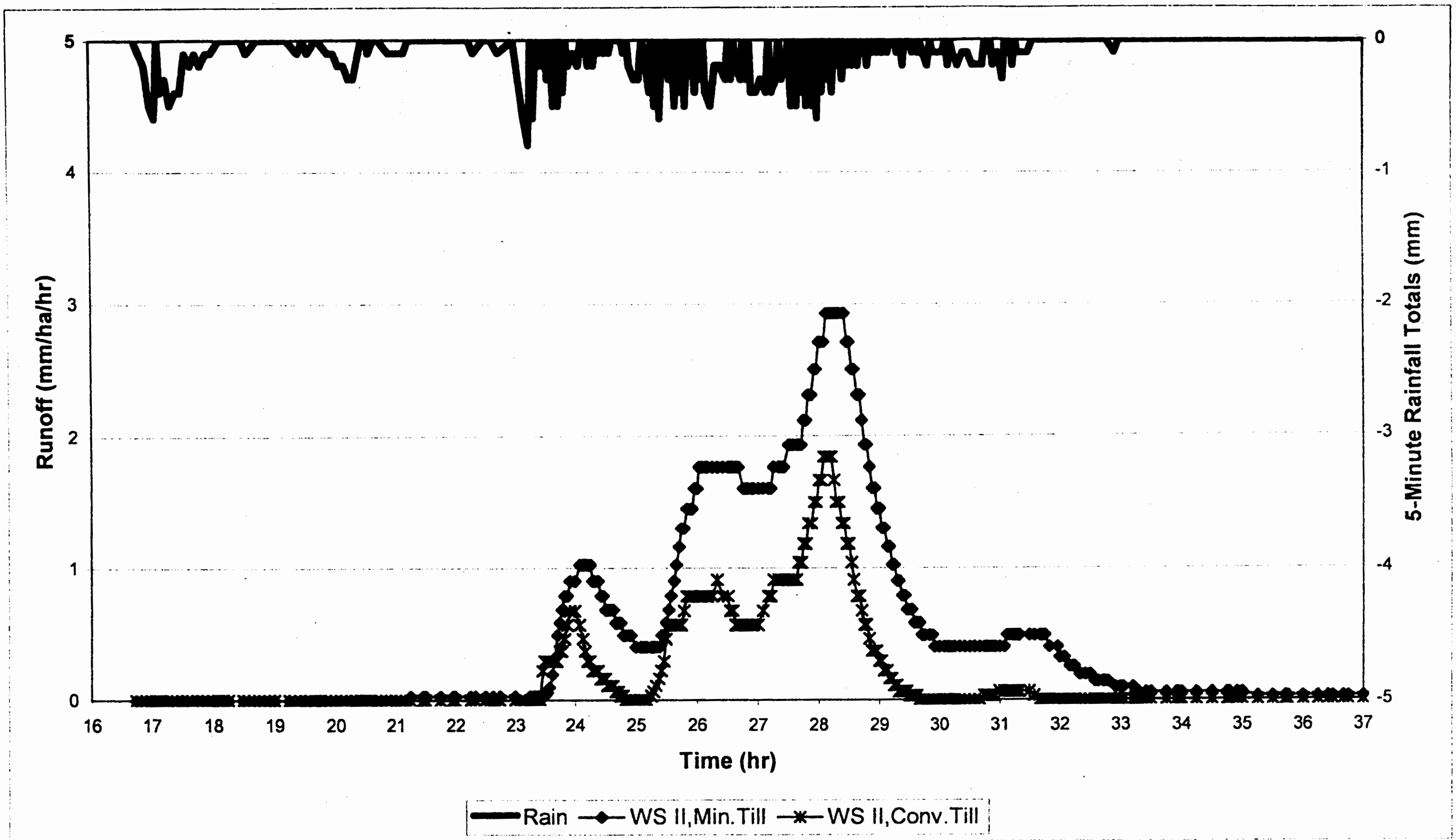

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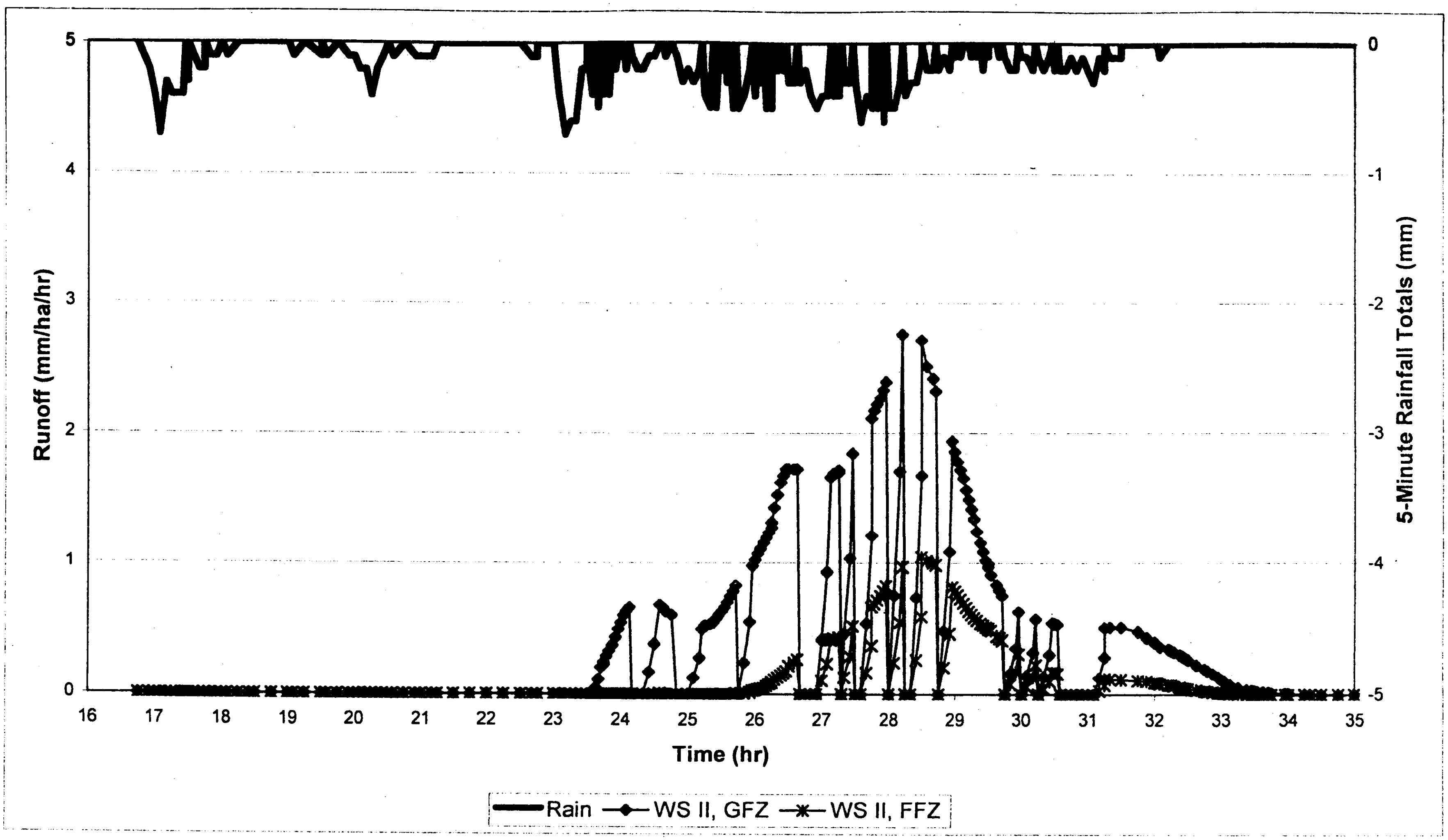

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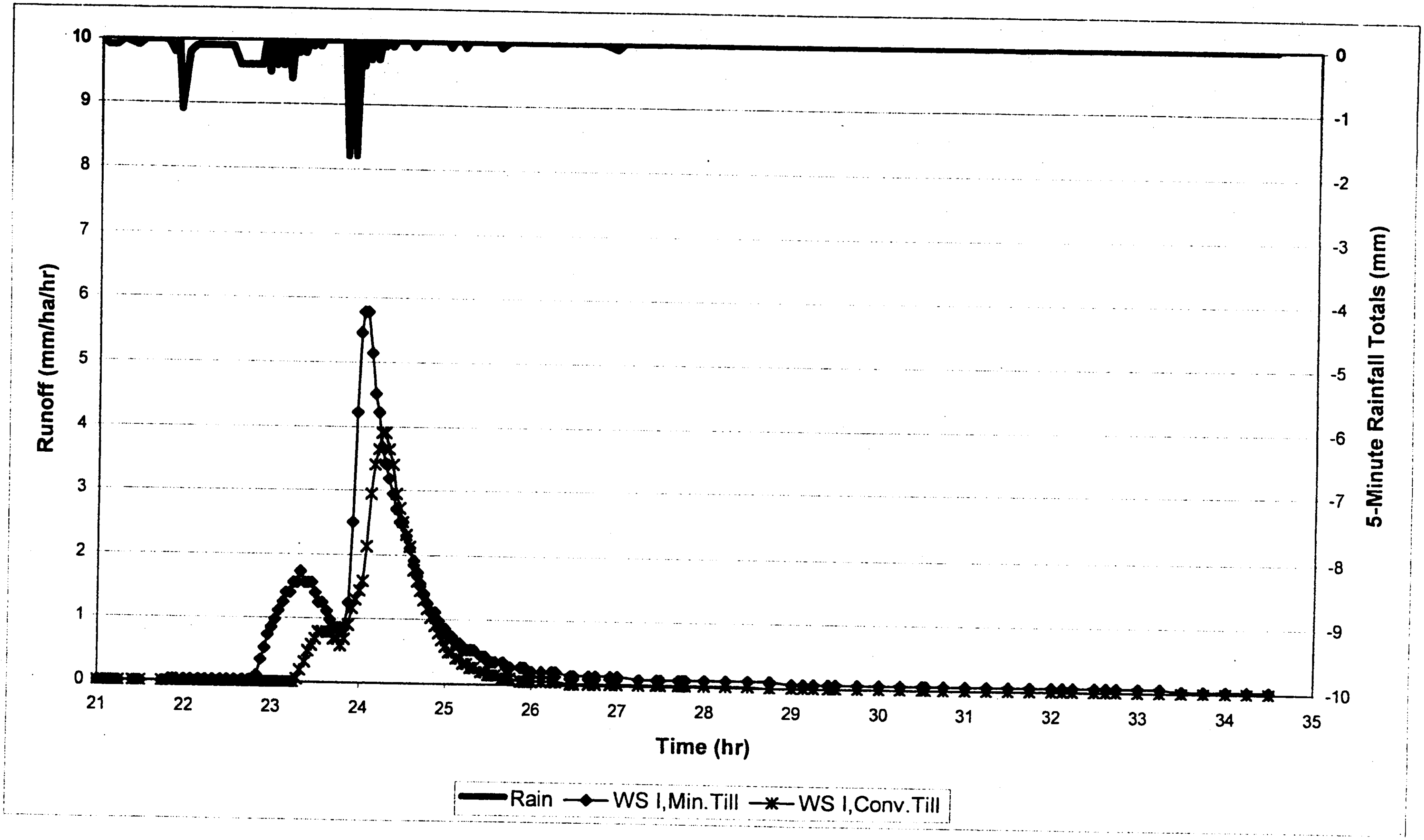
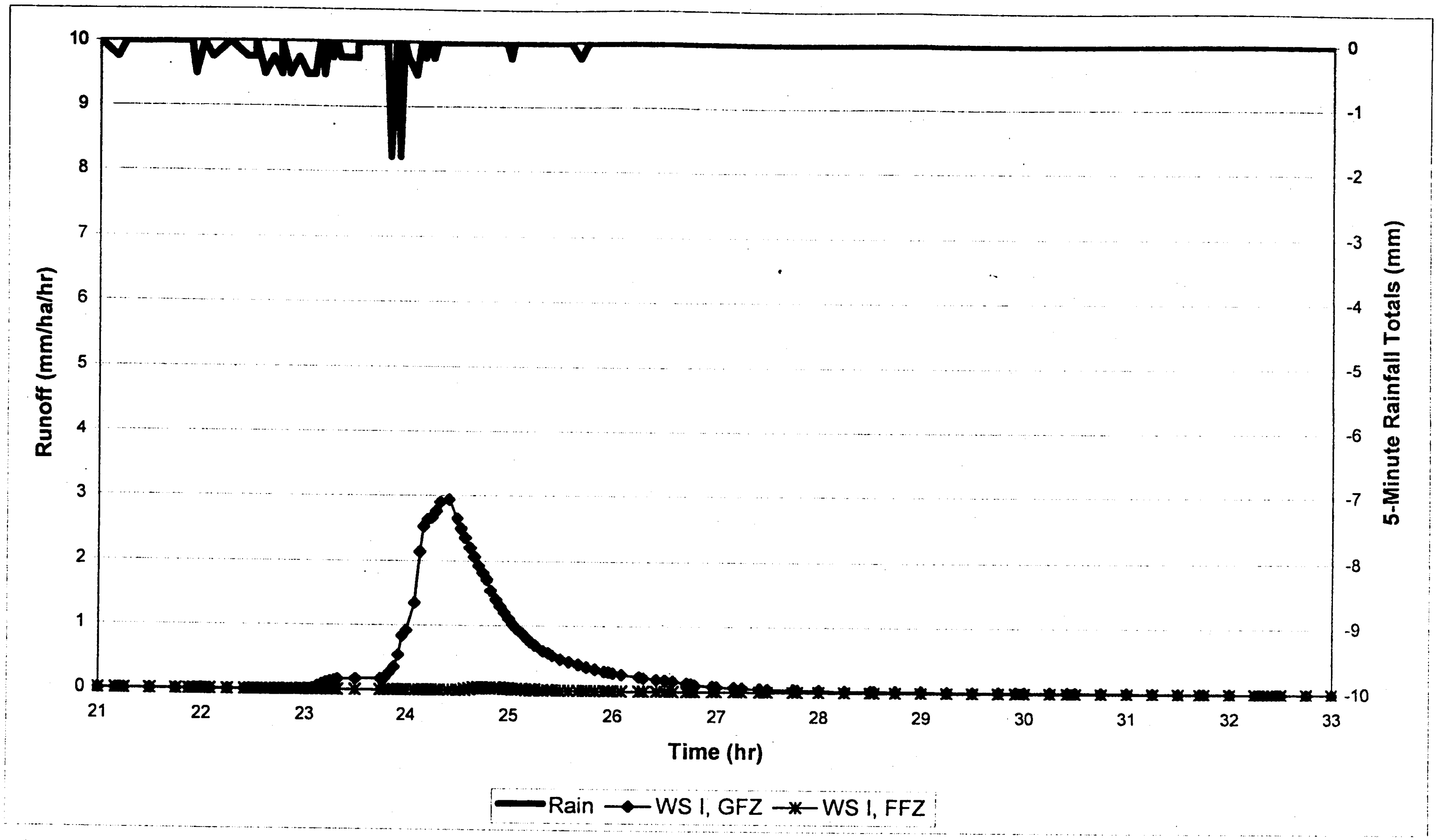


Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 214, 2000.



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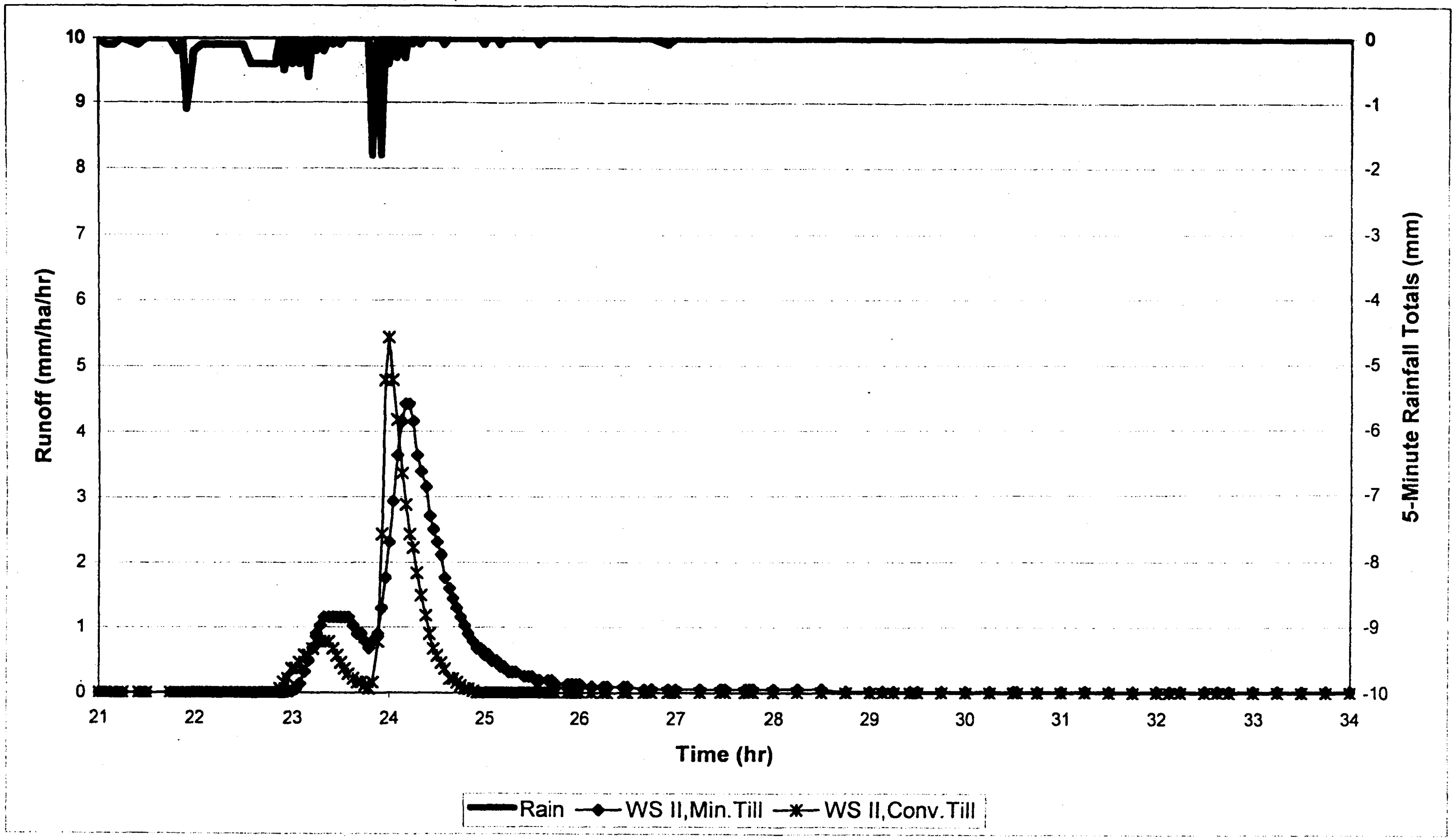

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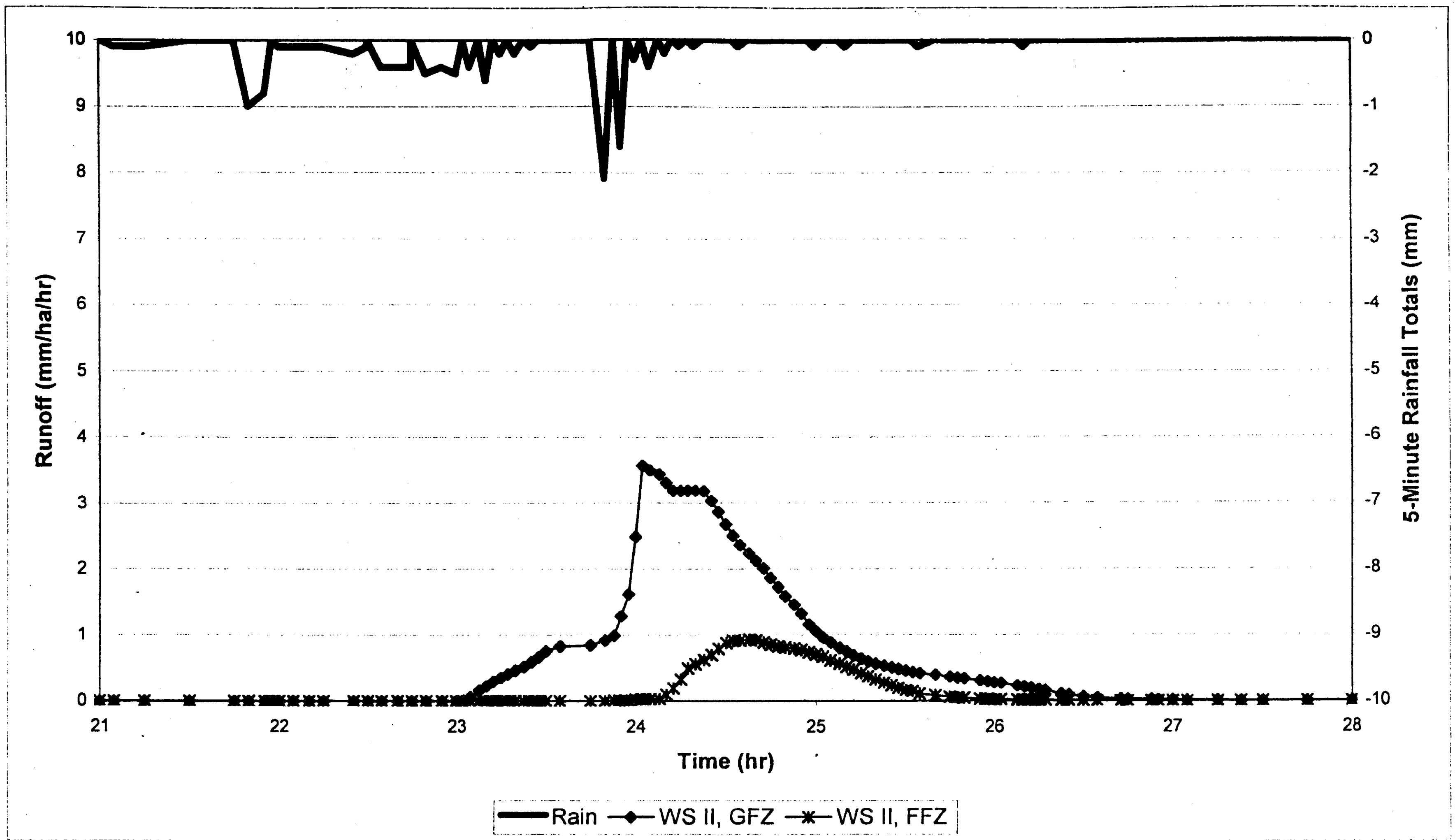

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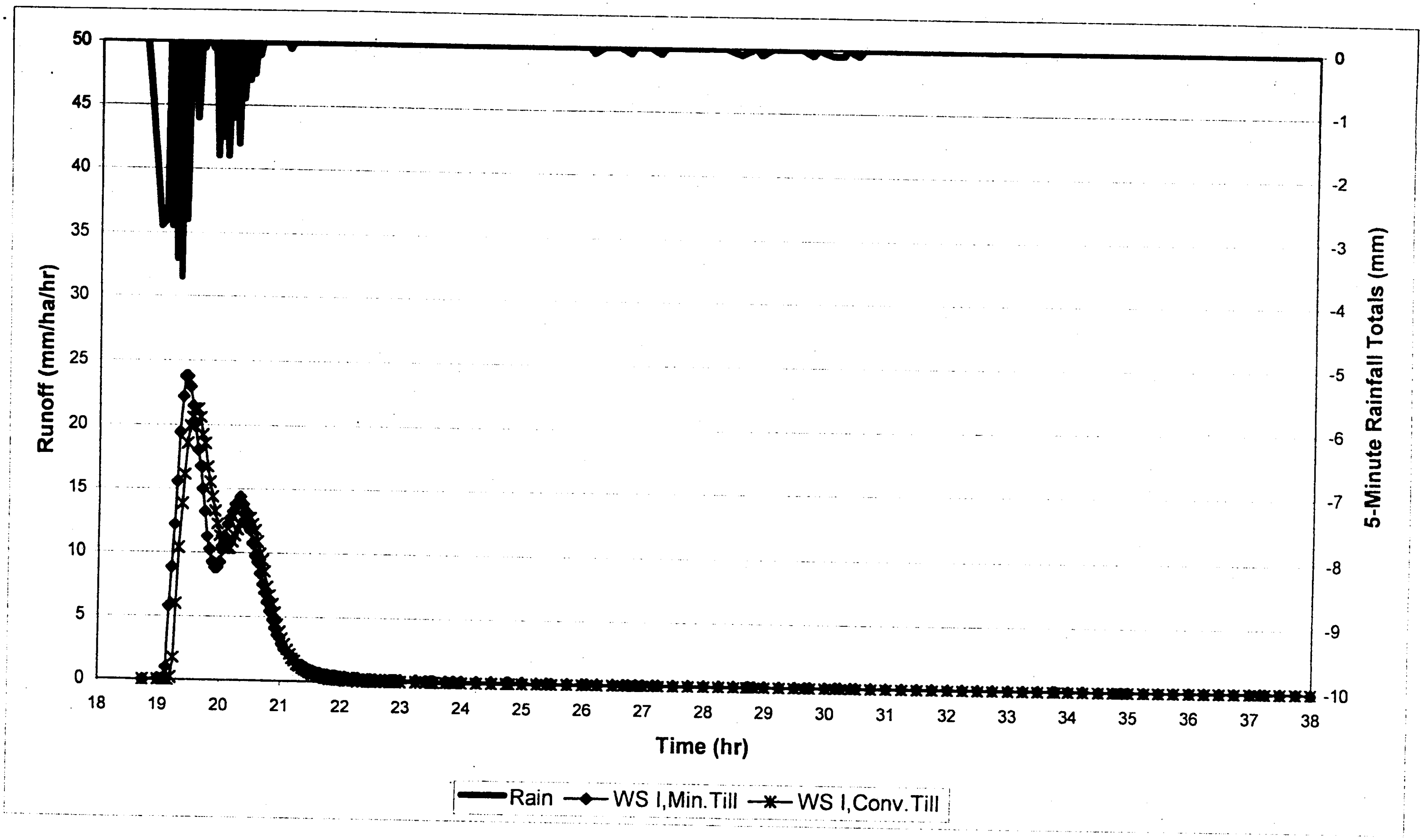

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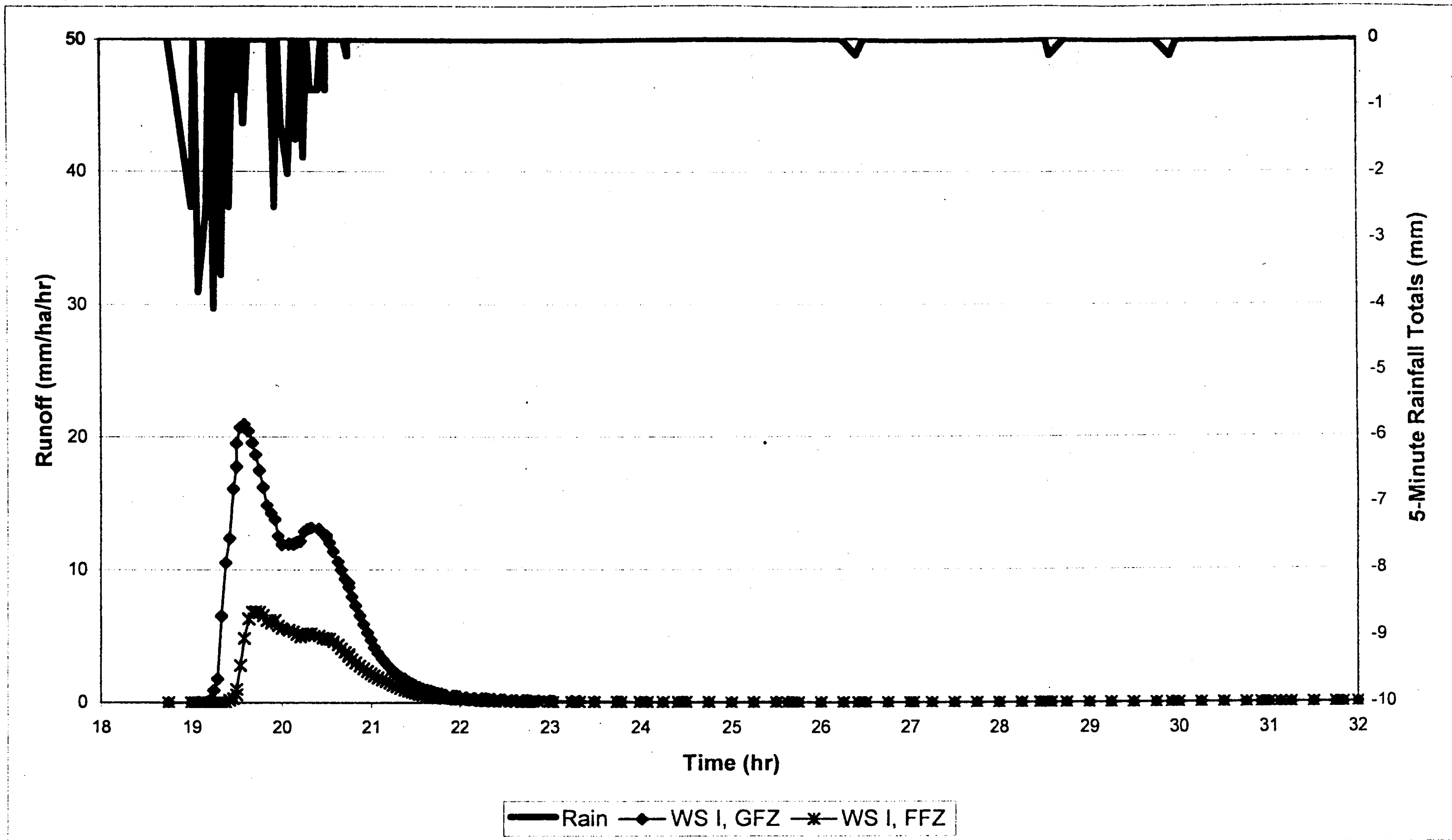

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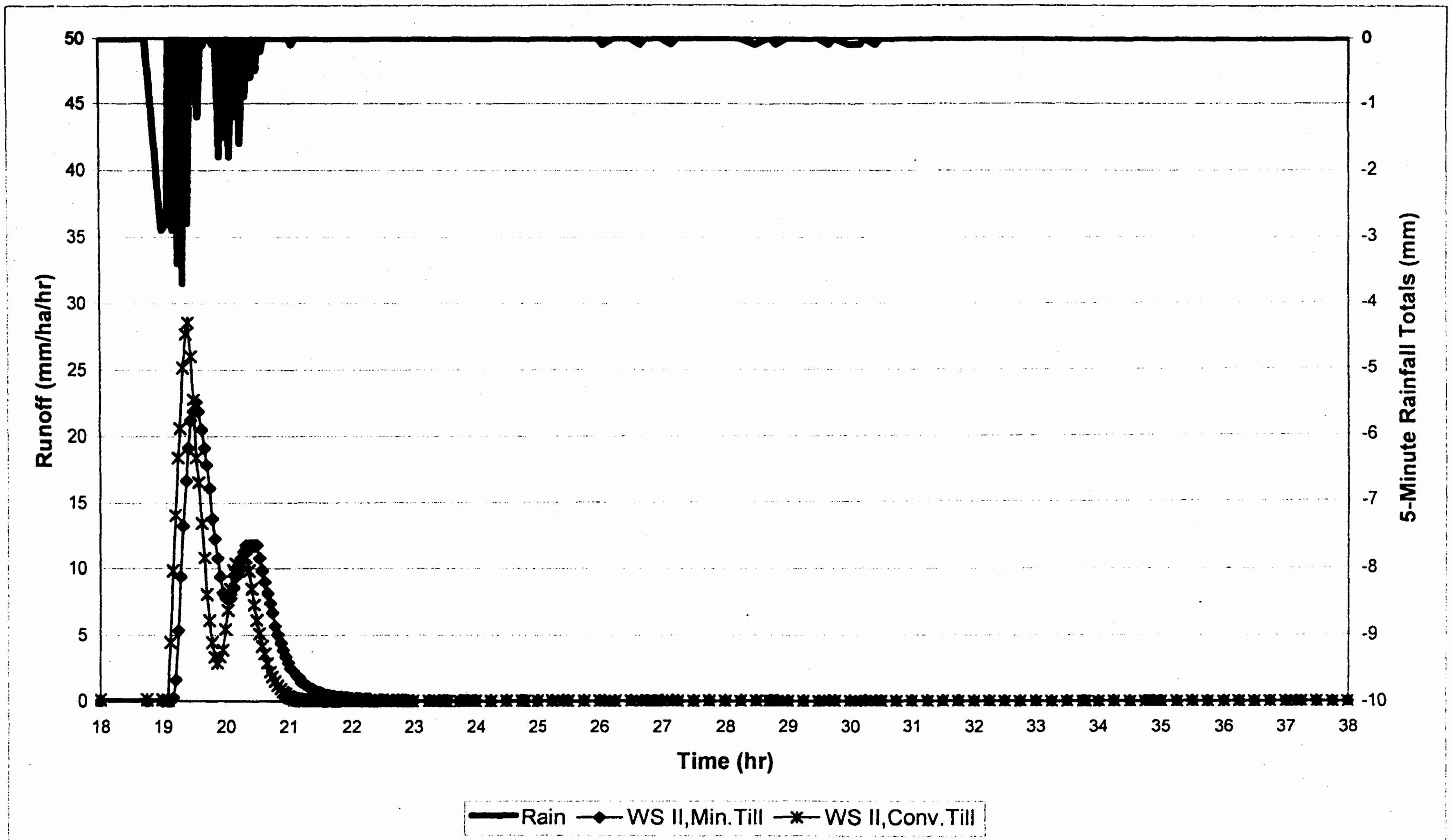

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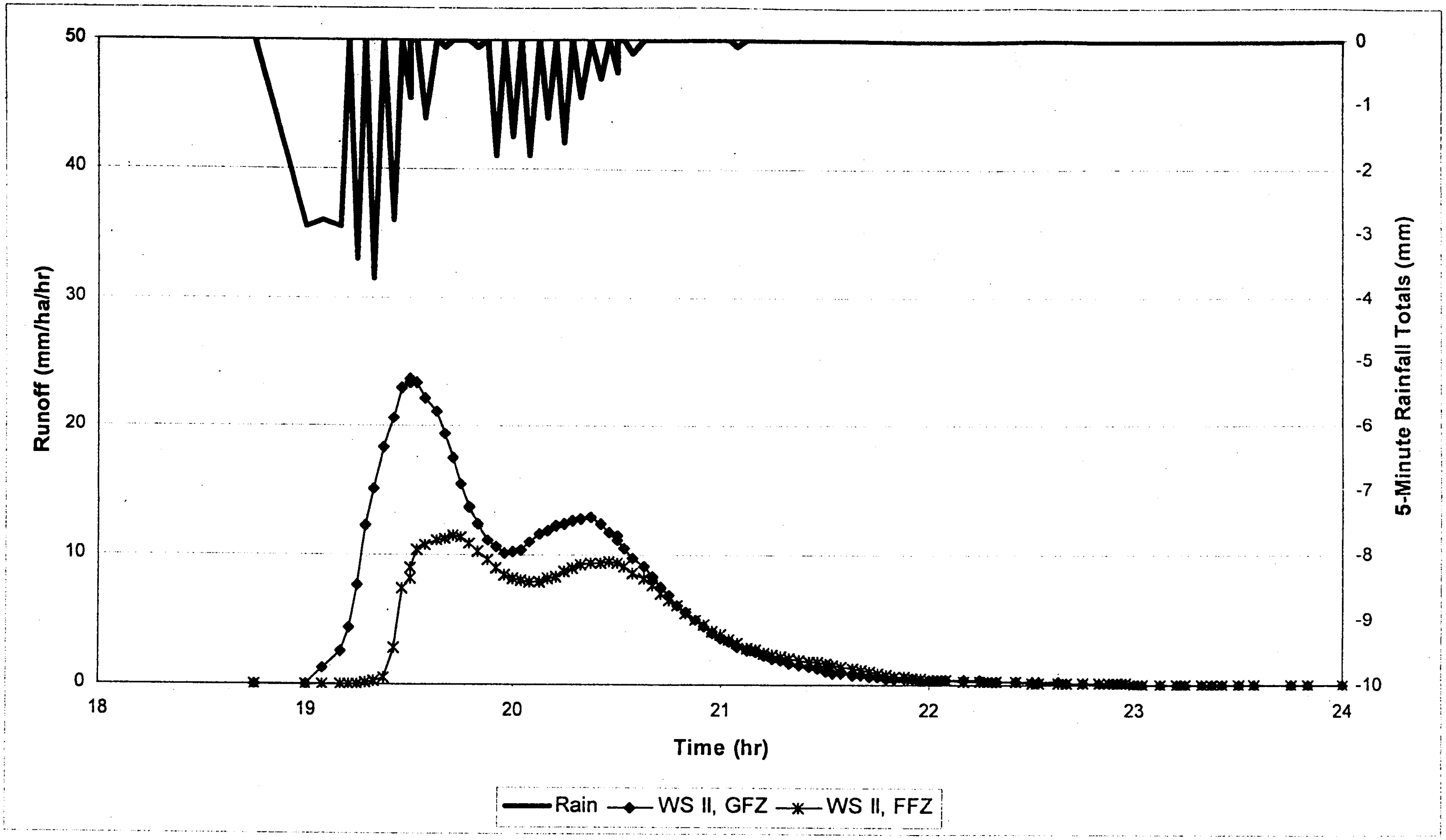

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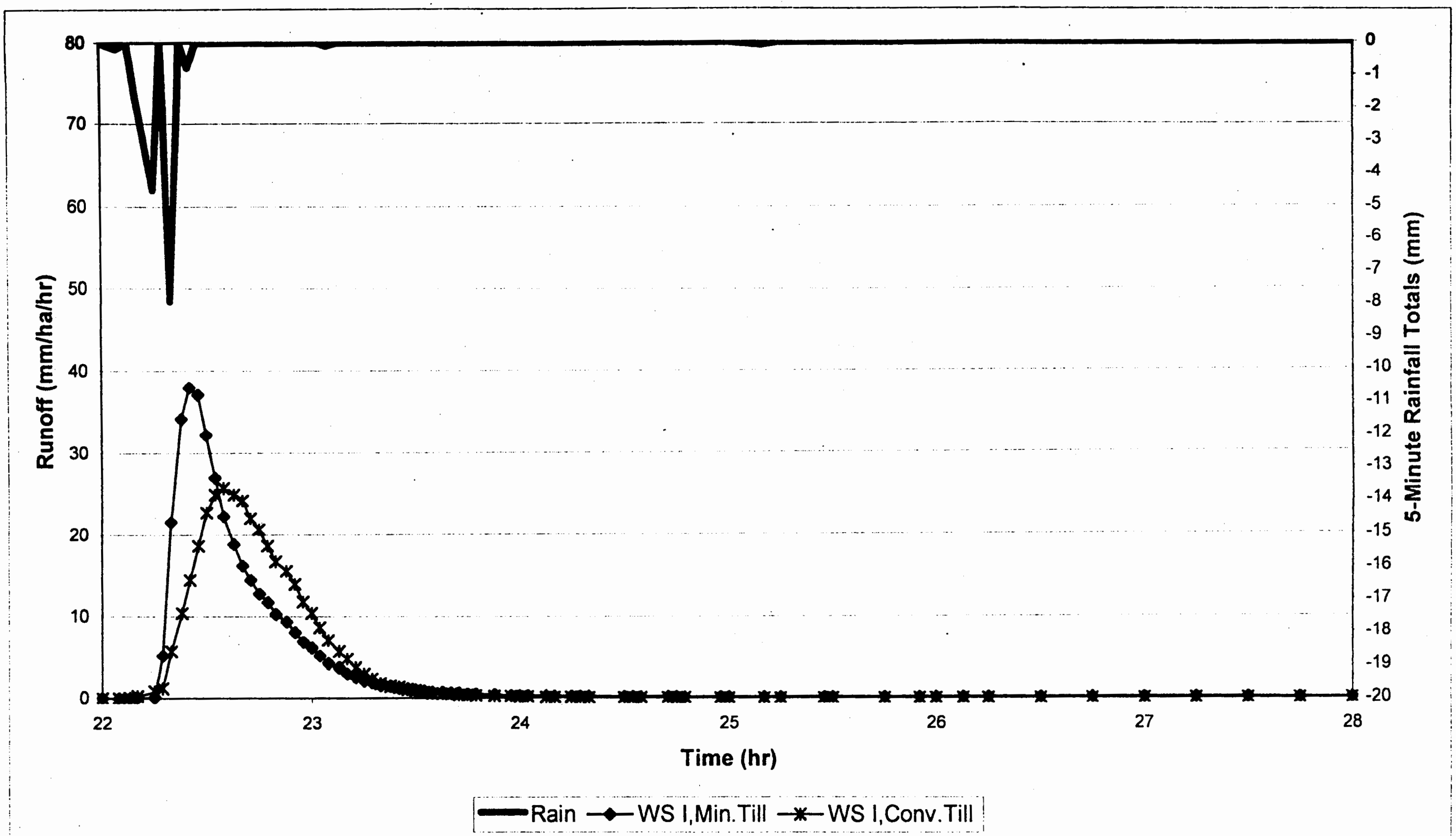

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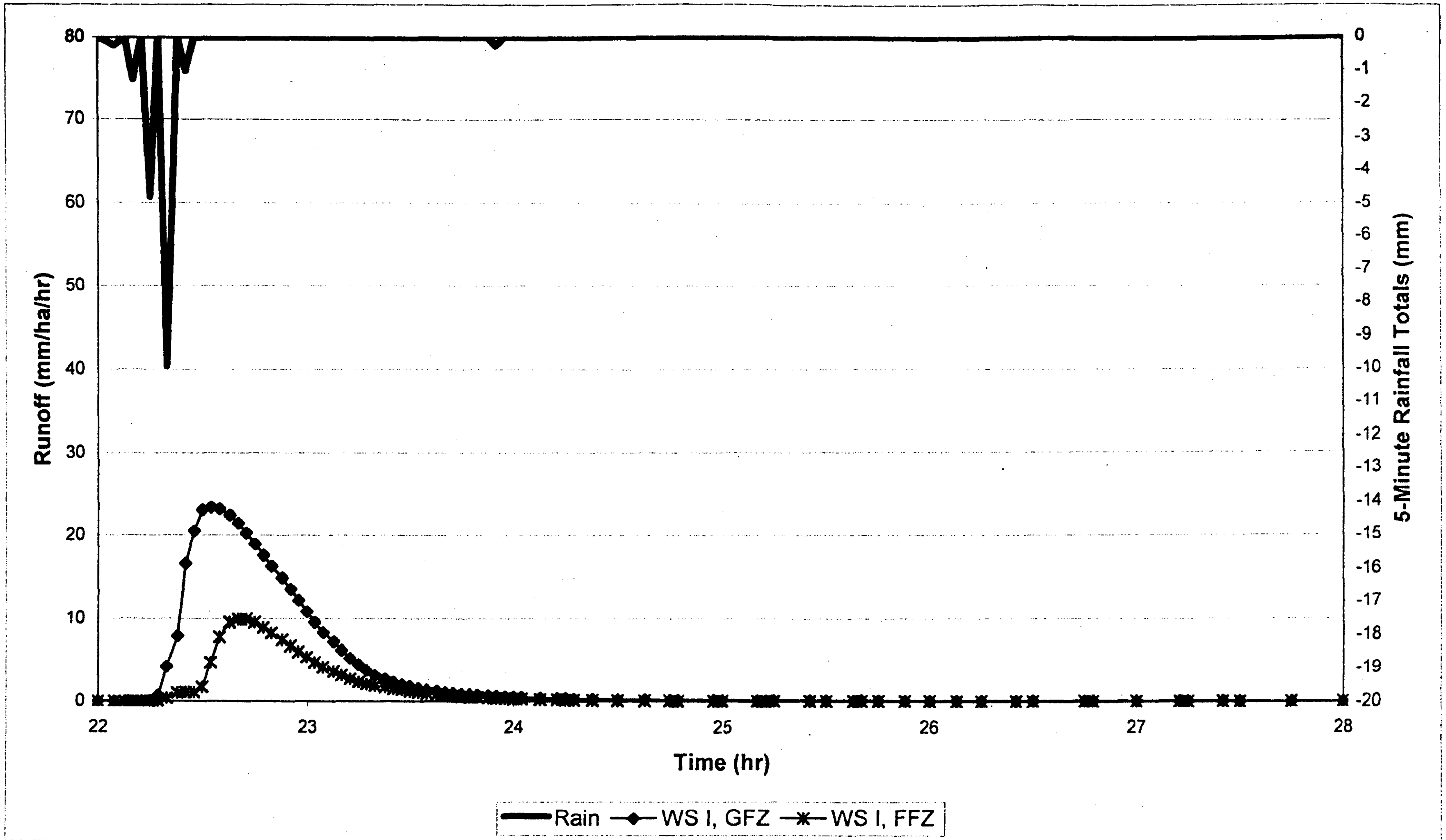

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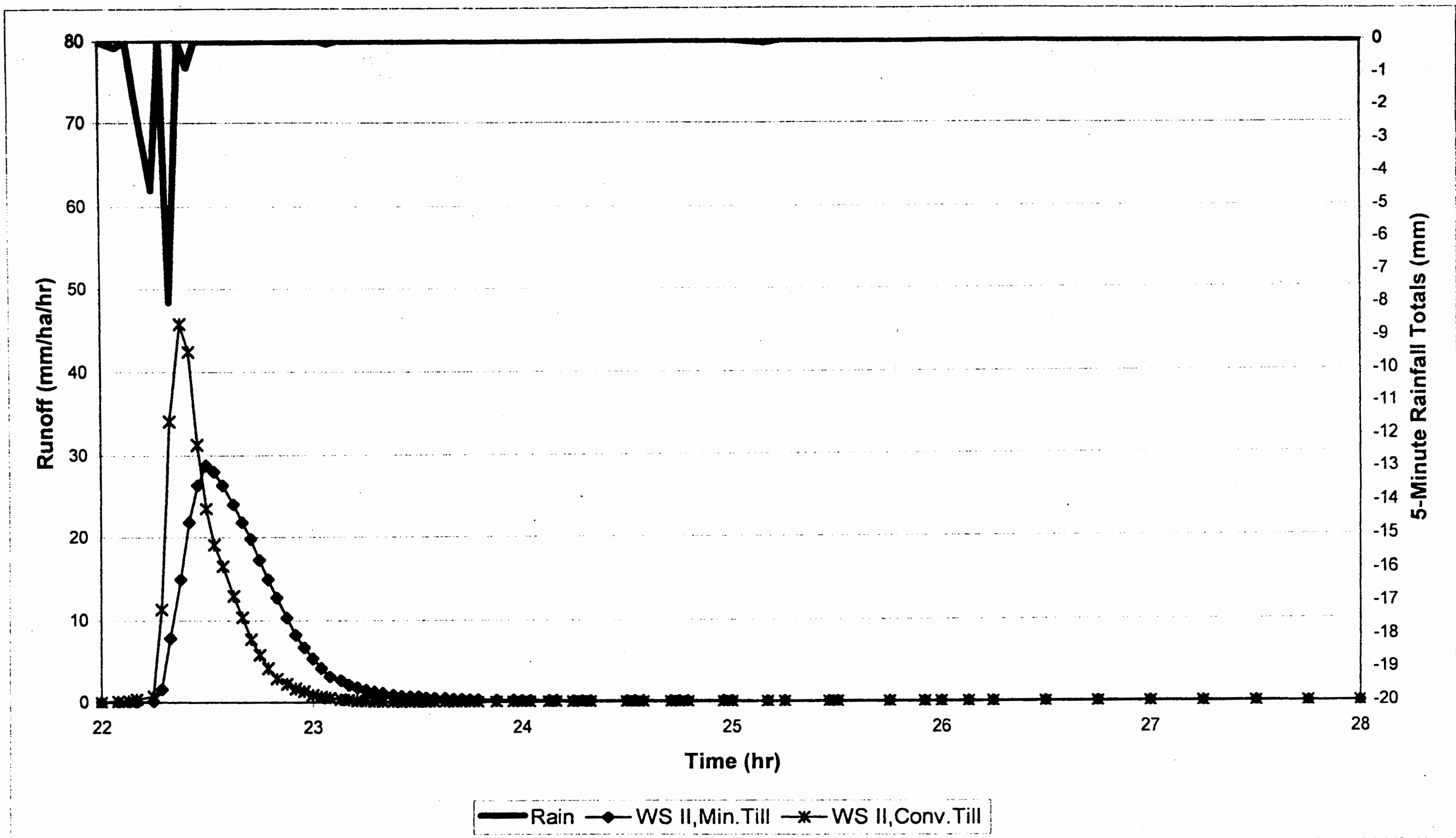

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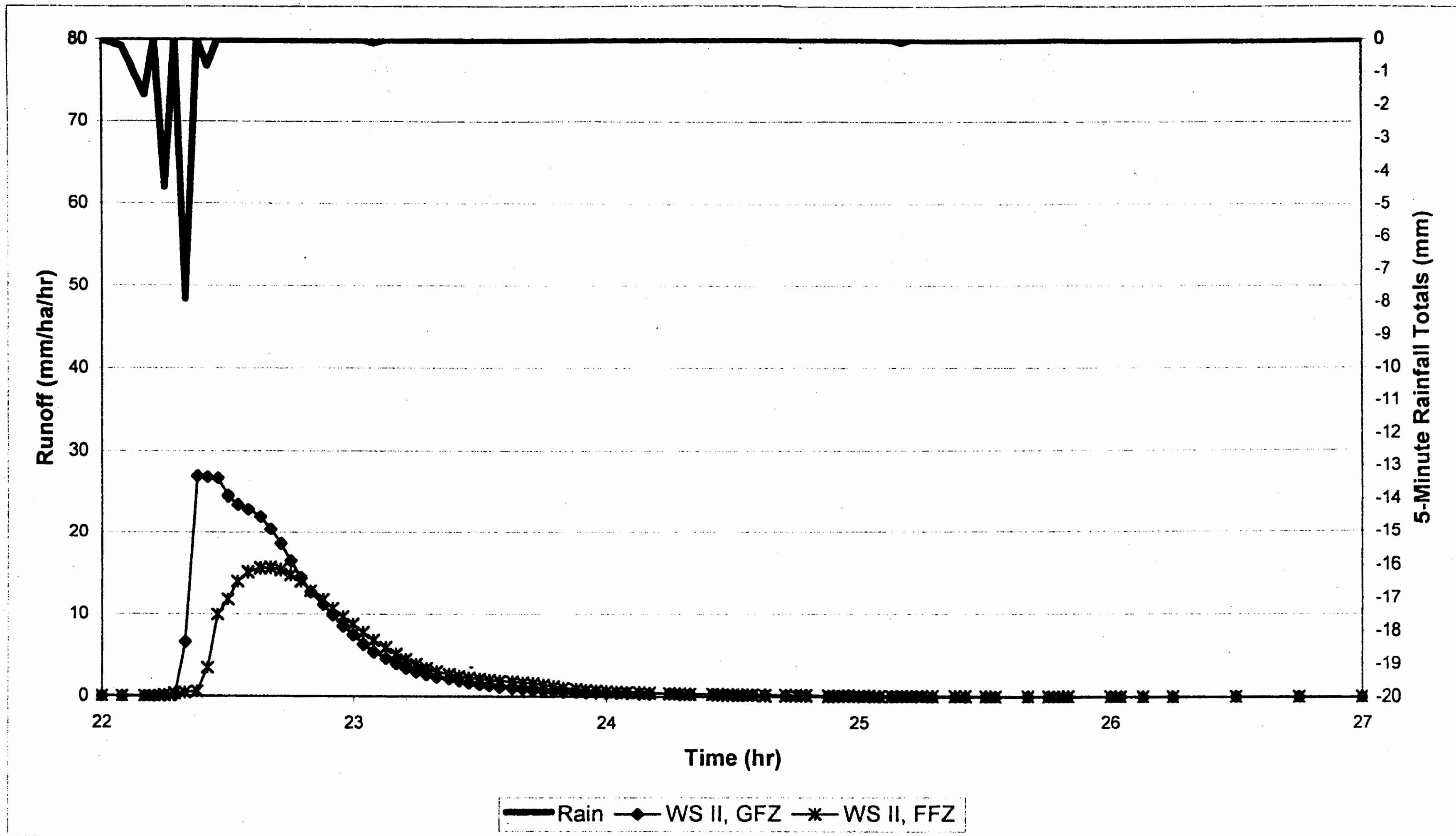

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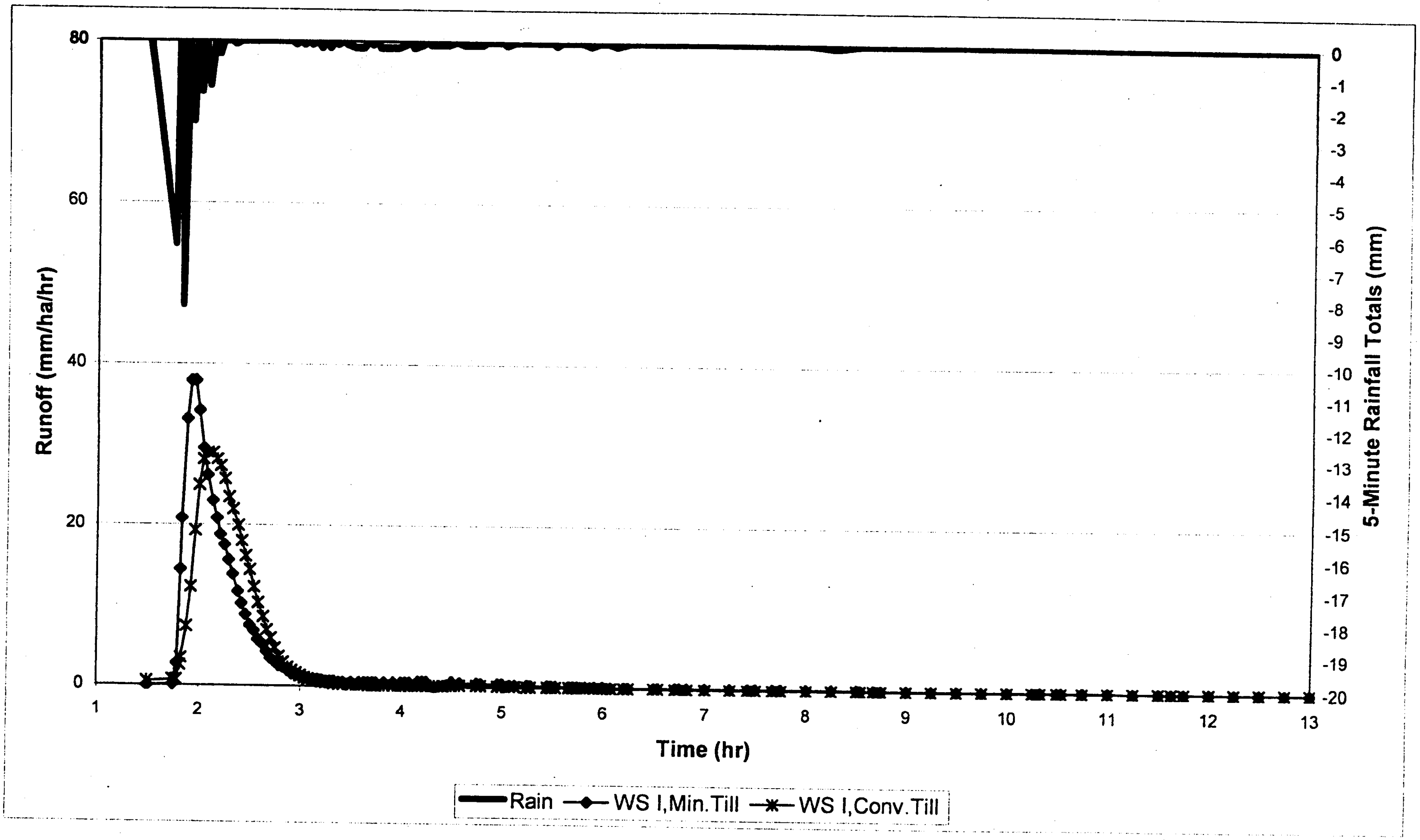

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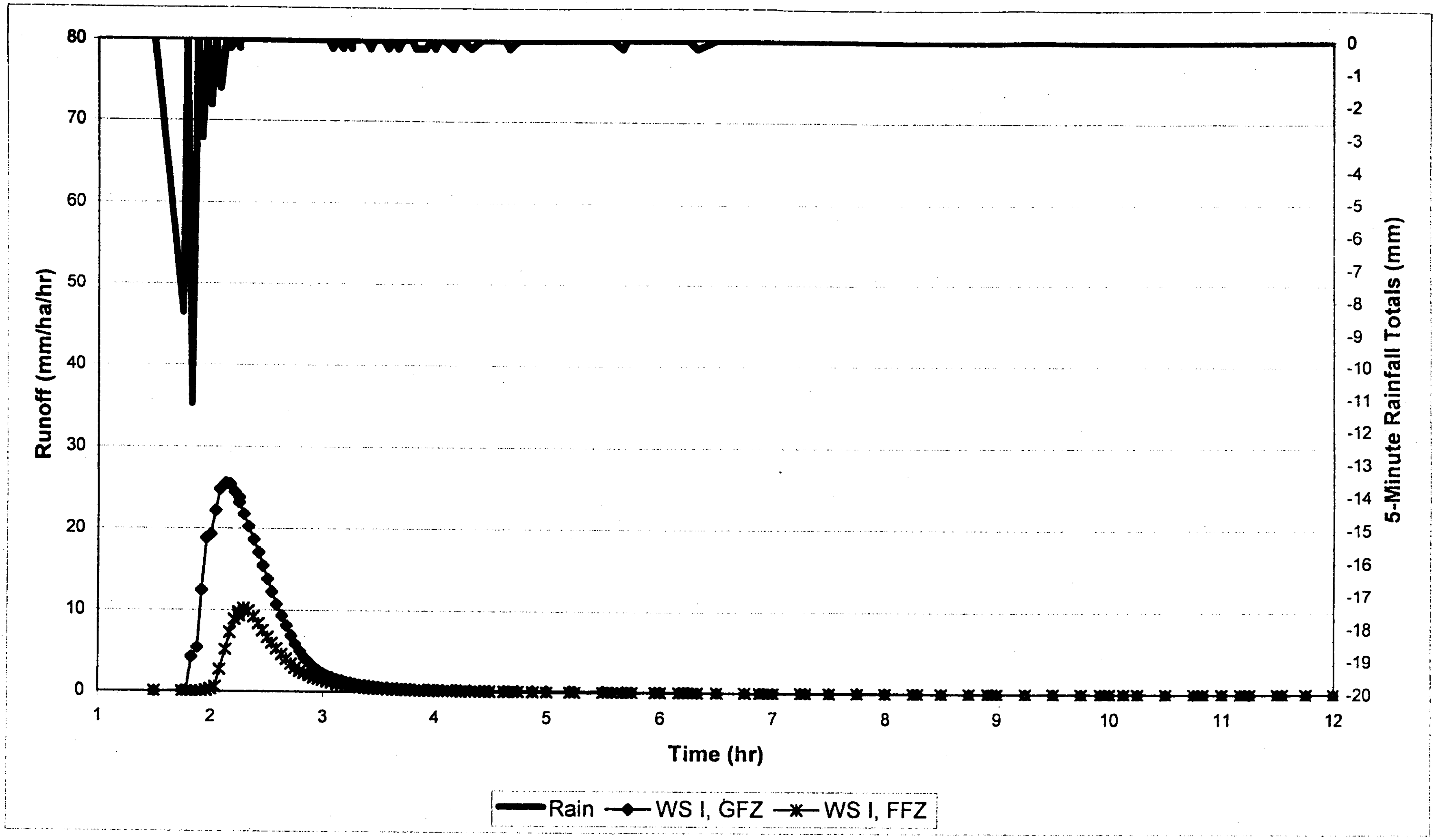

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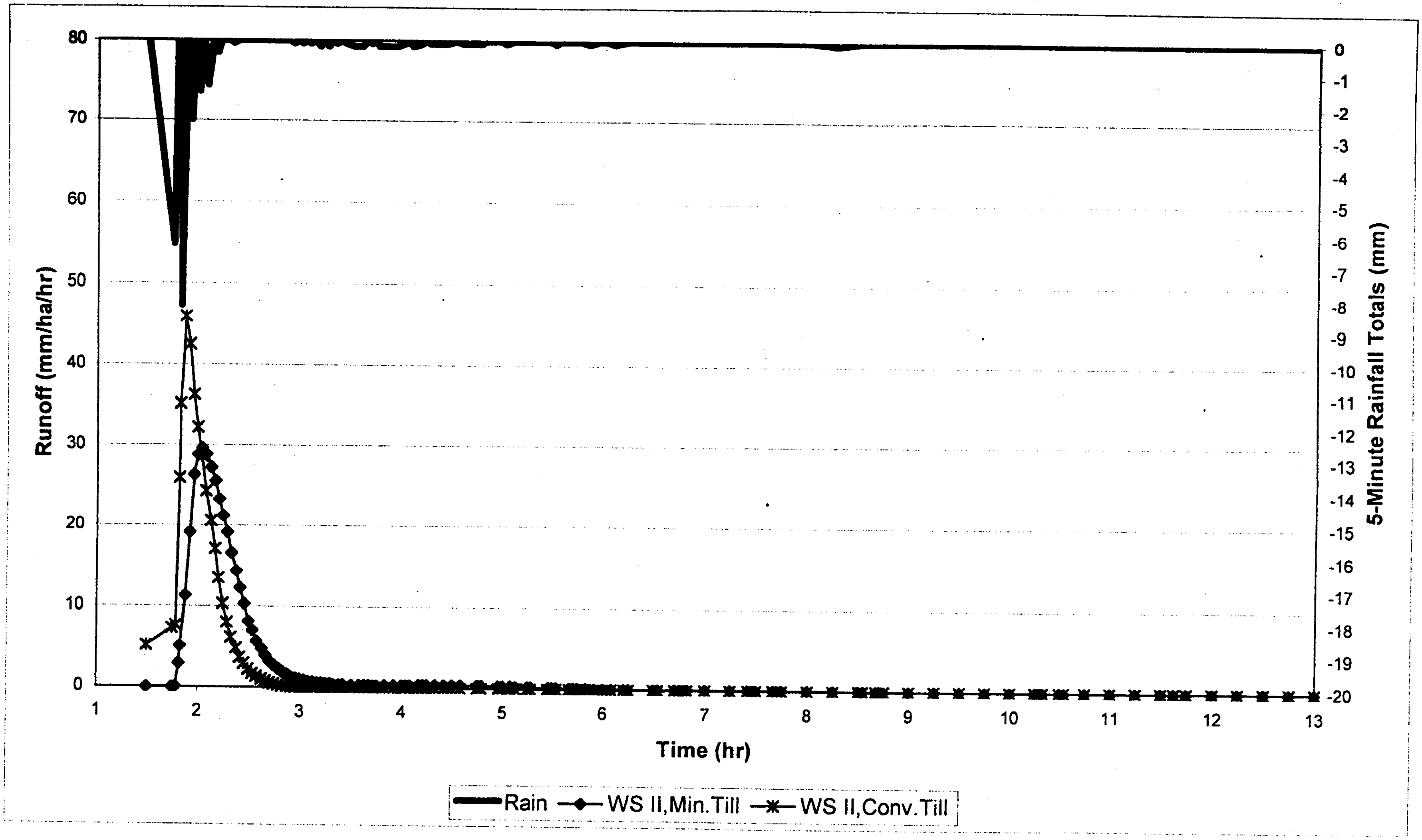

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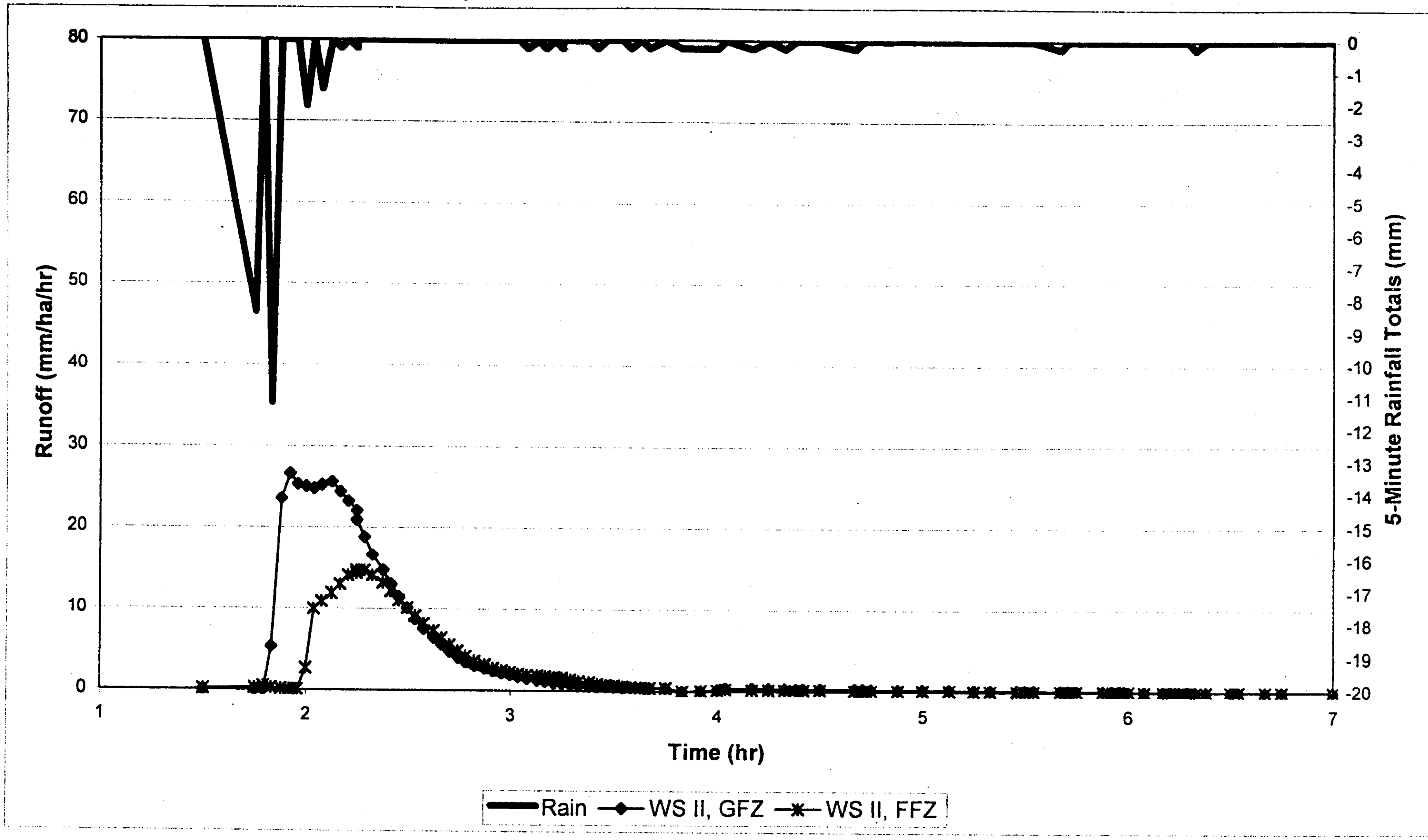

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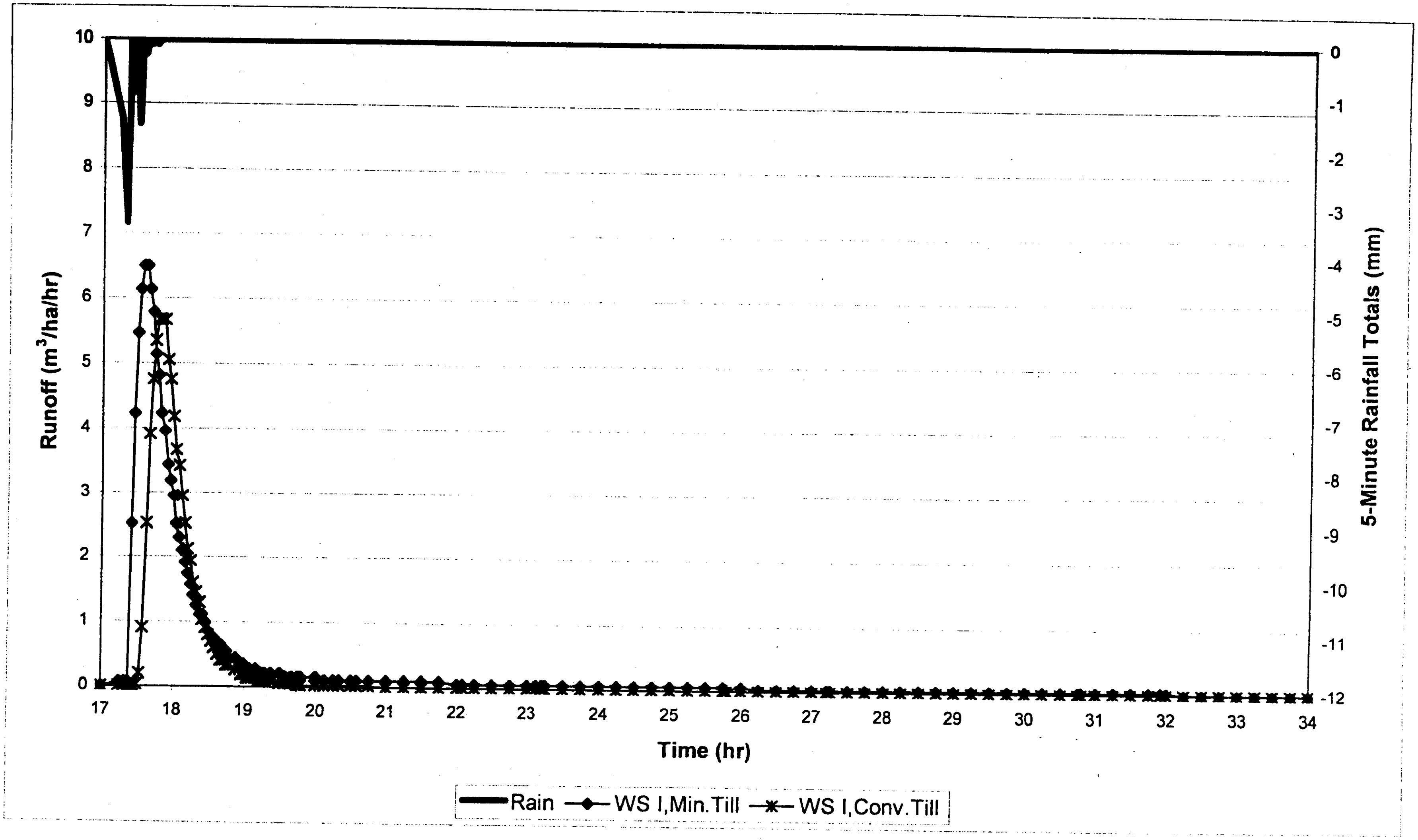

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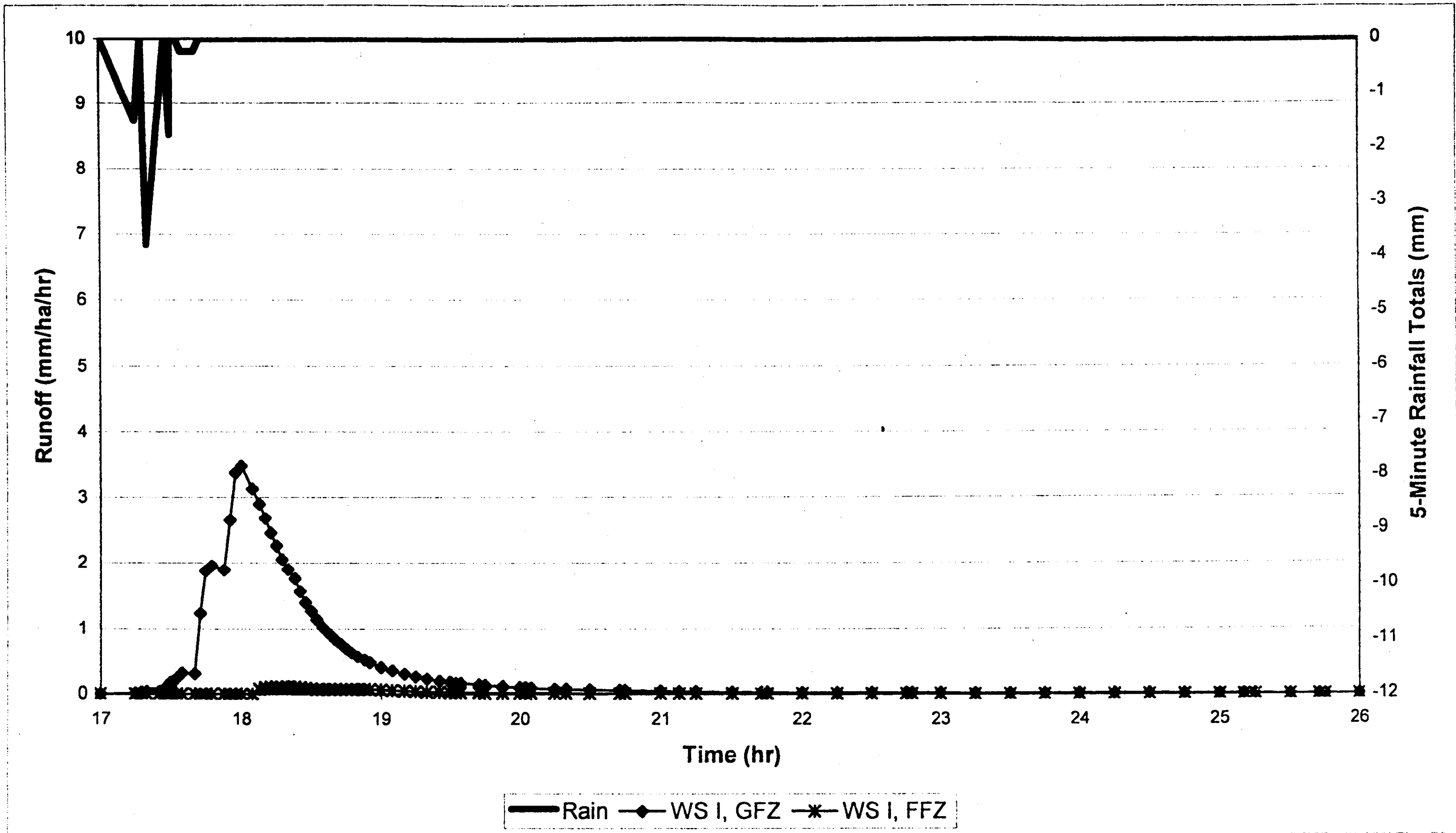

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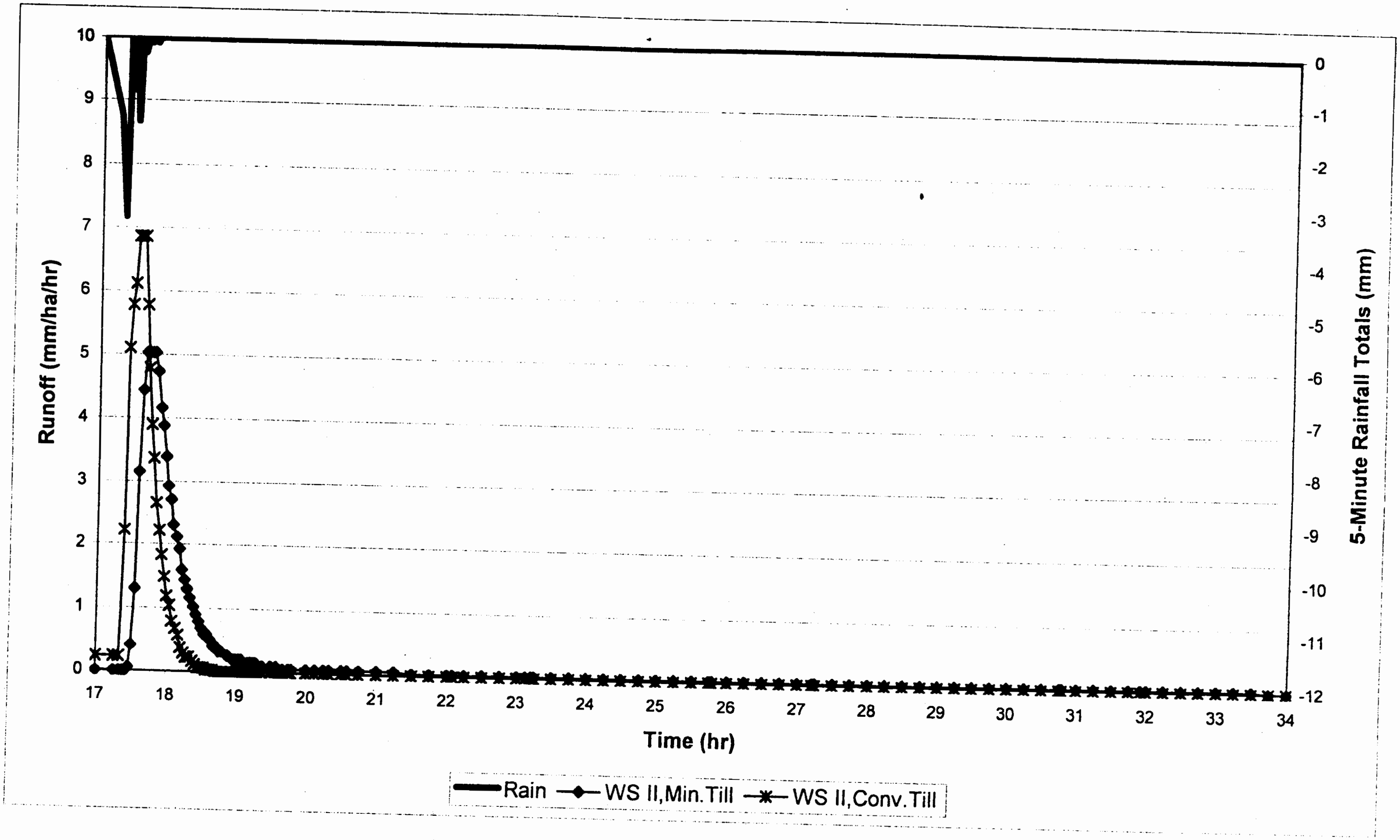

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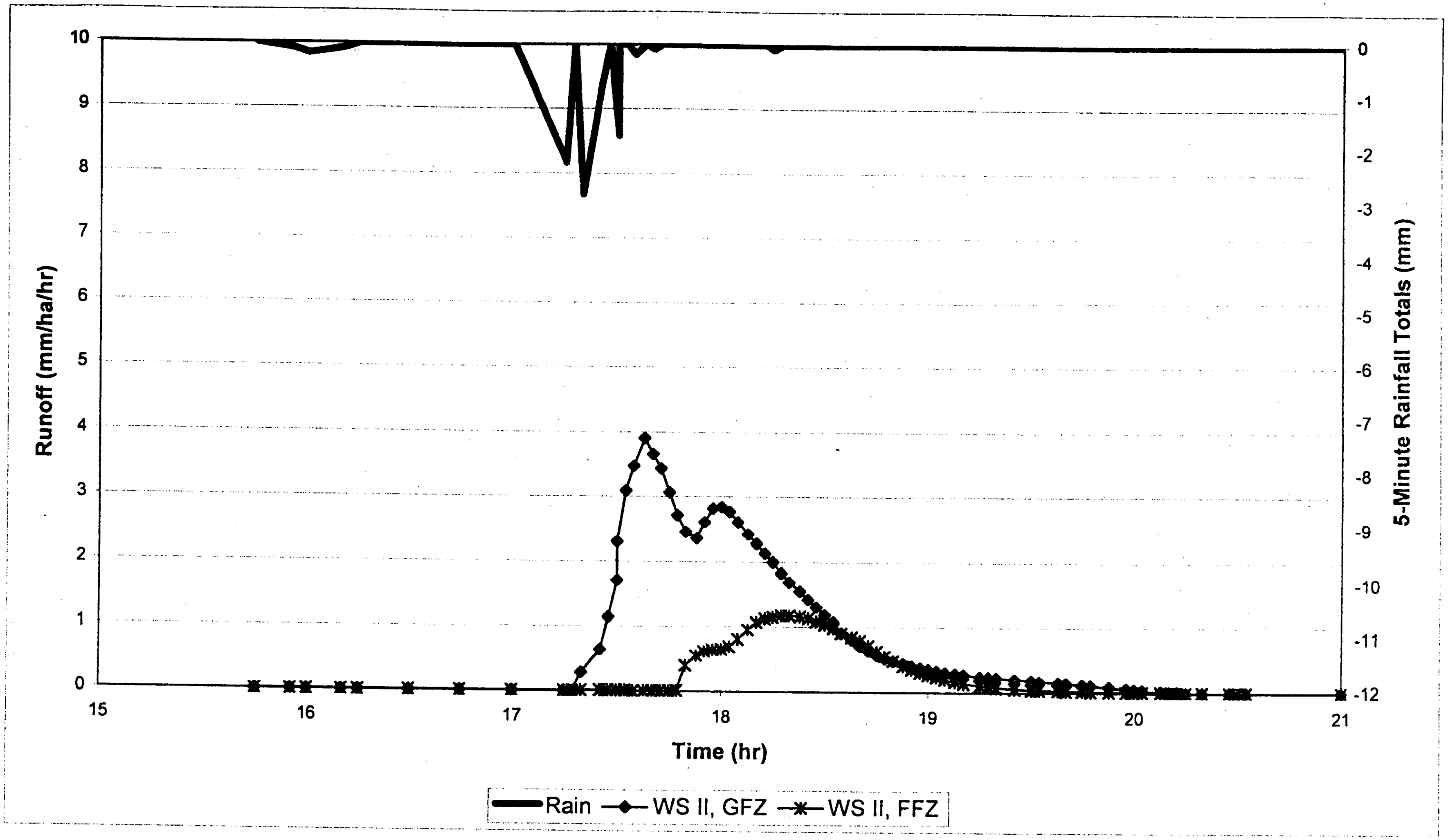

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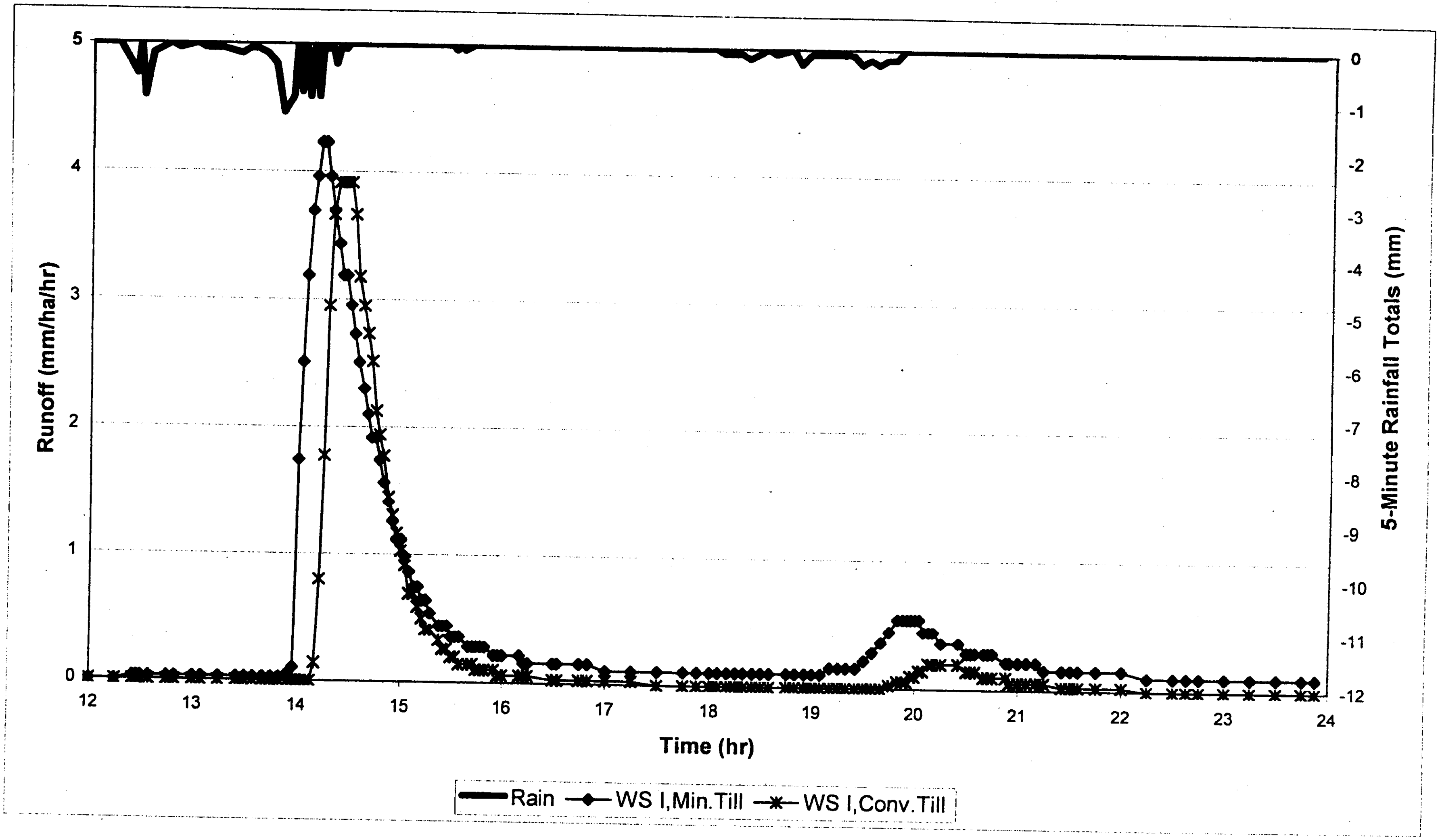

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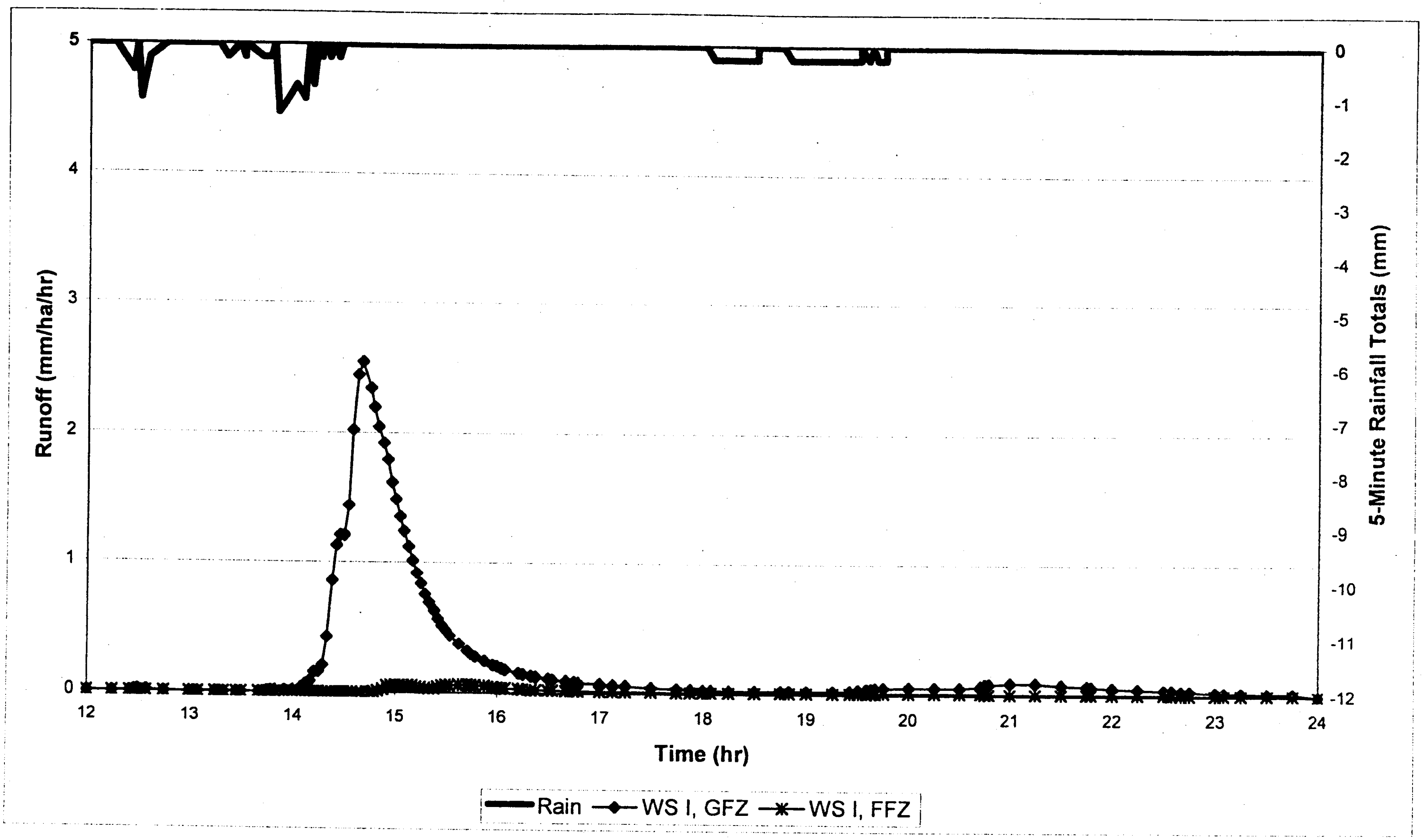
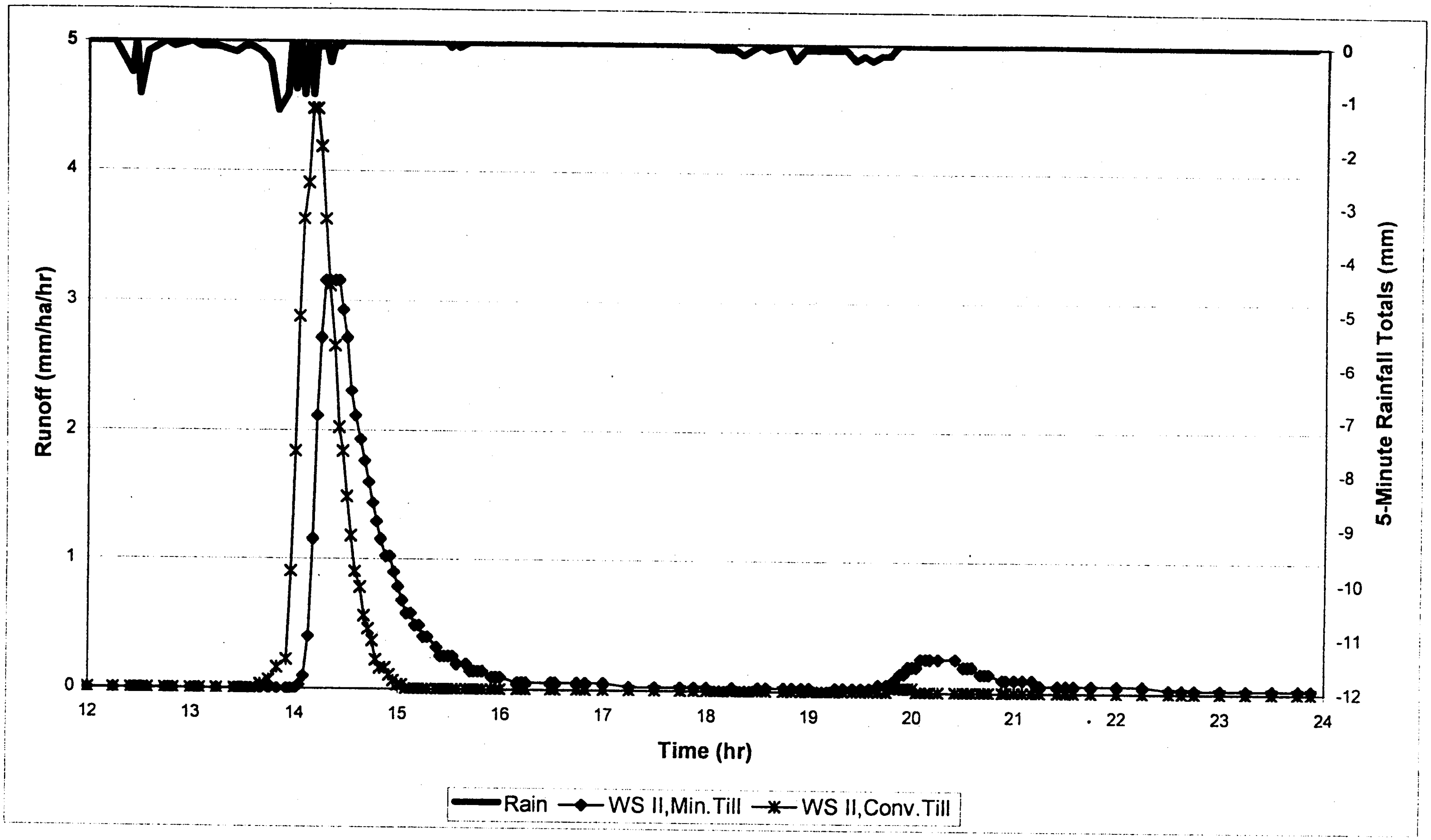
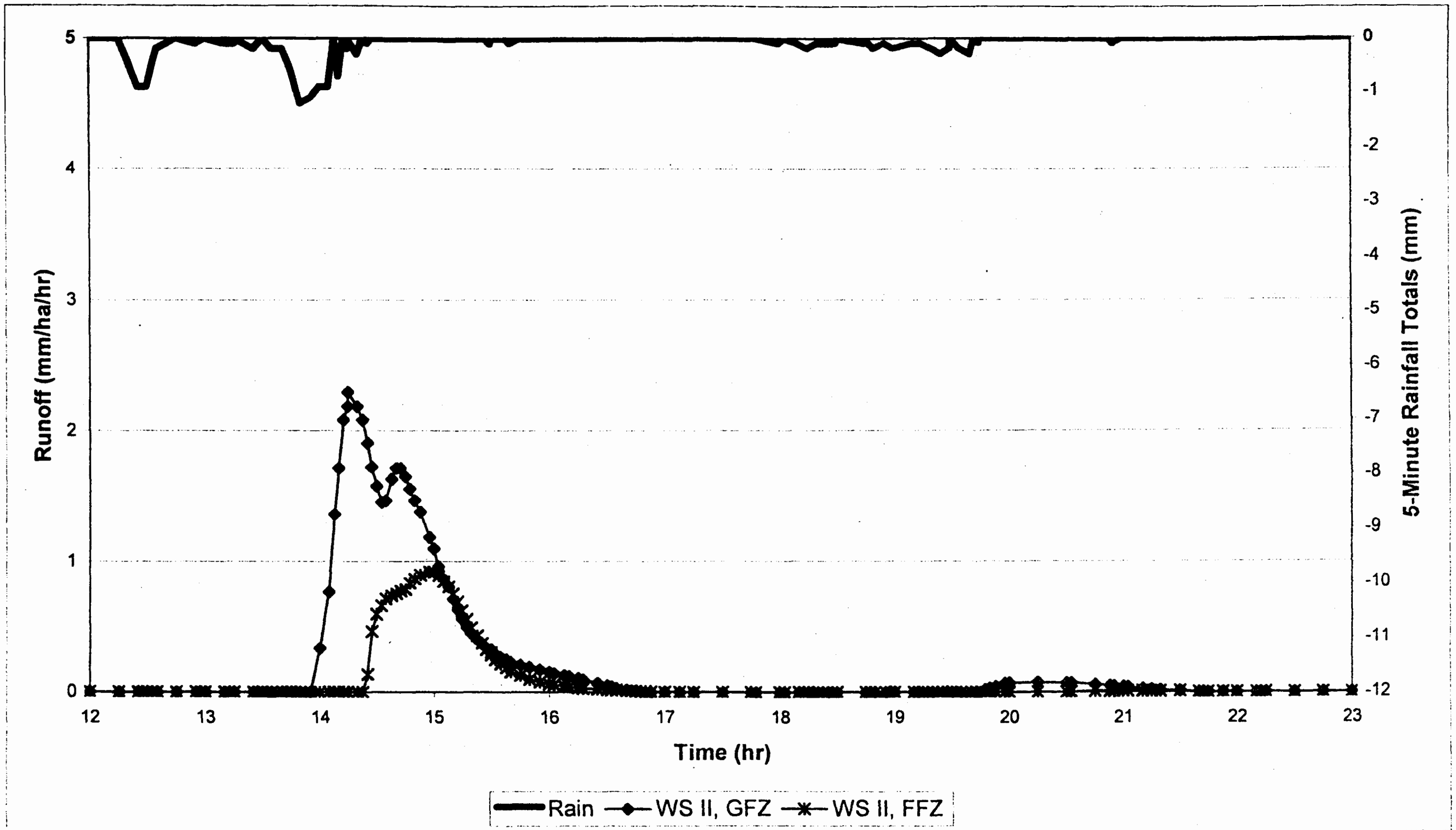


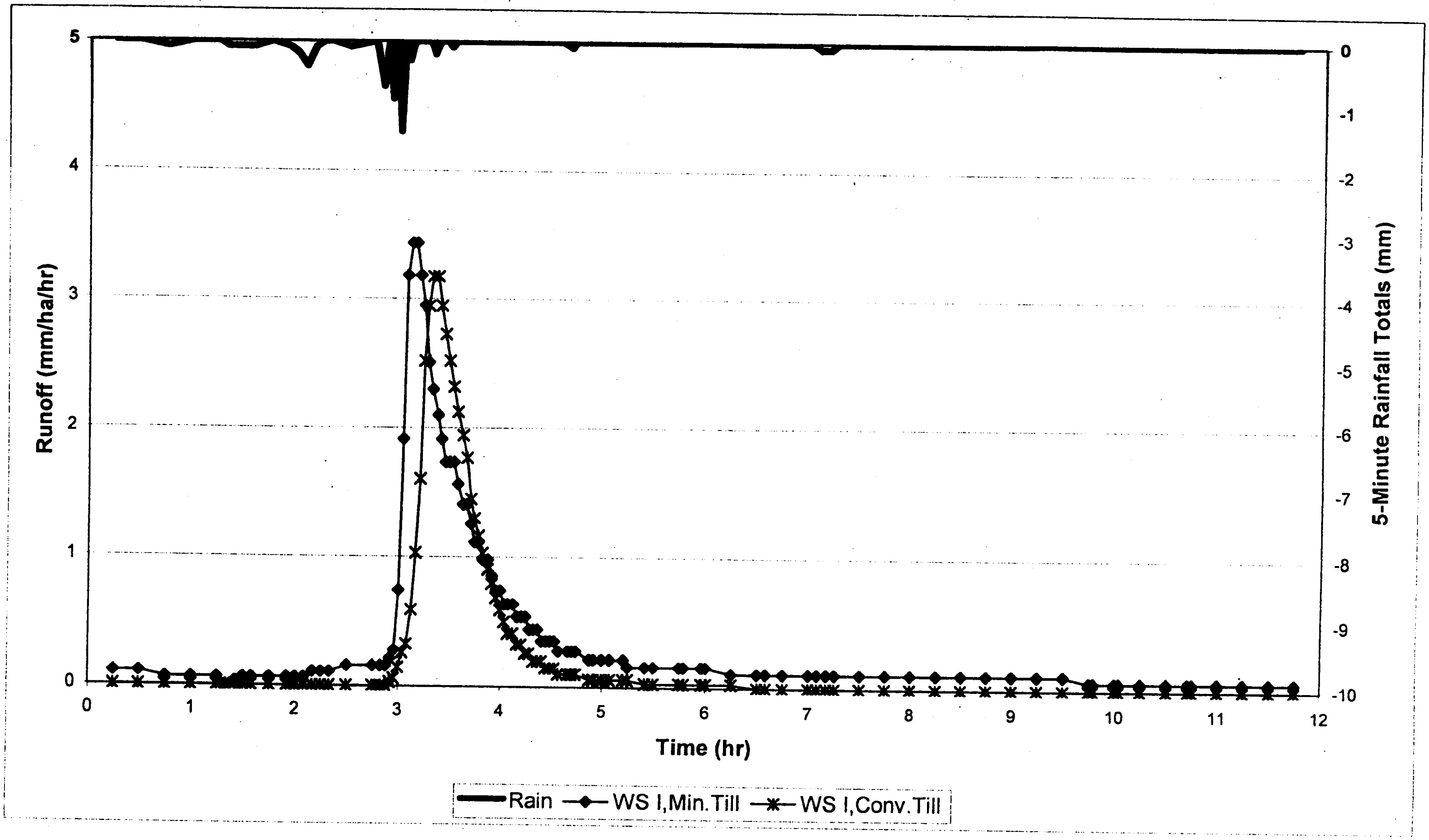
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 243, 2000.



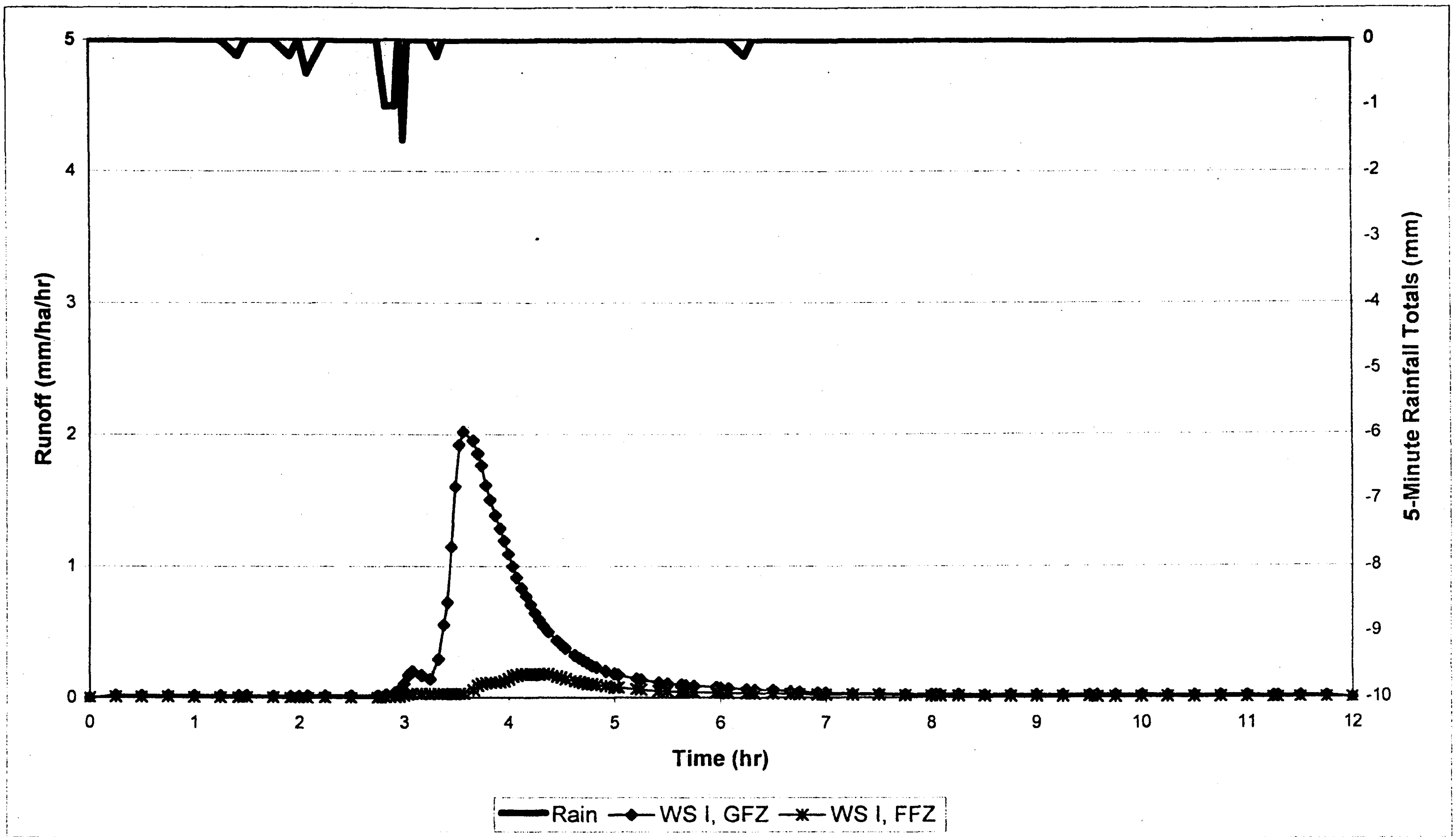
Storm Hydrograph for Oxford Tobacco Fields, Watershed II. Julian Day 243, 2000.



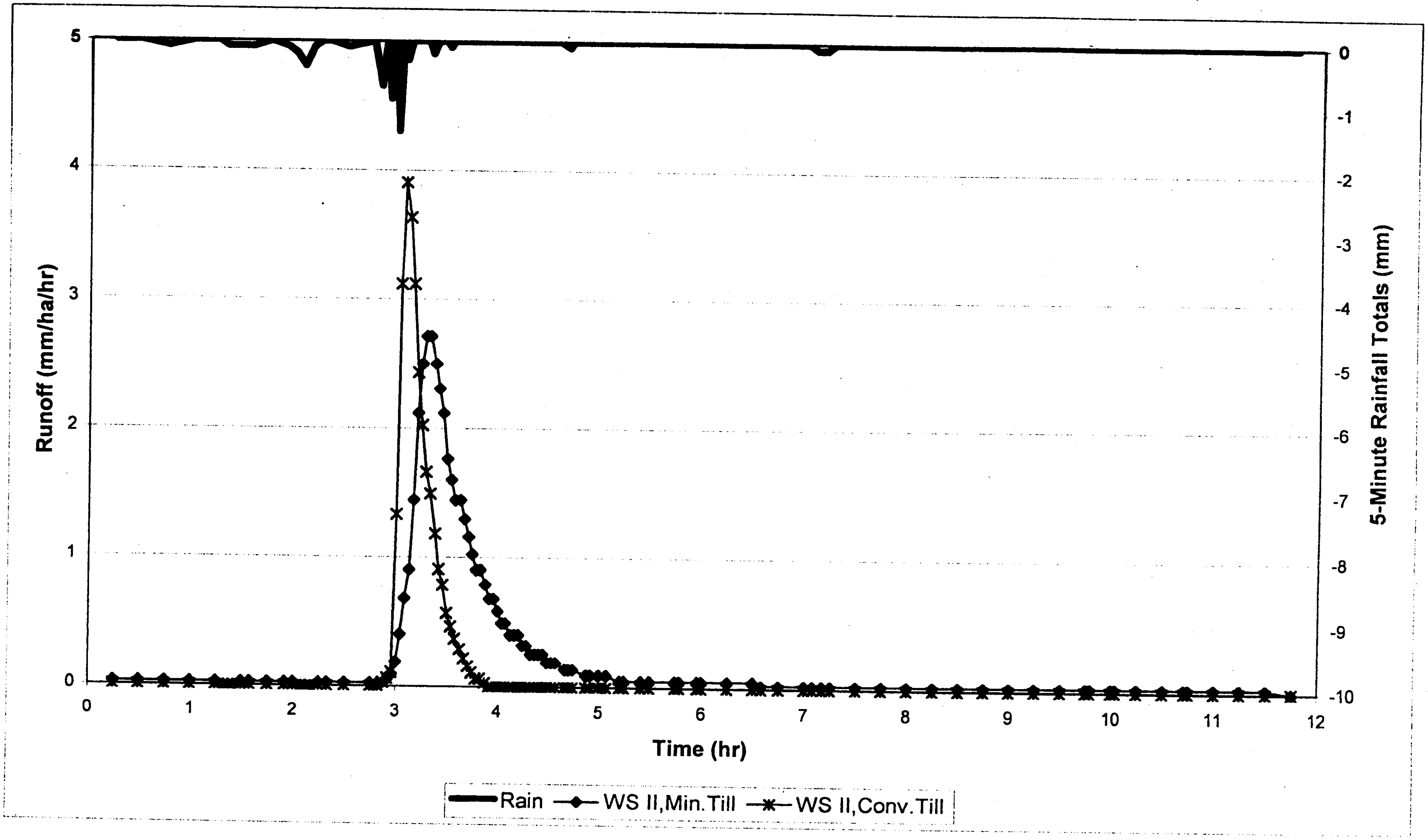
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 243, 2000.



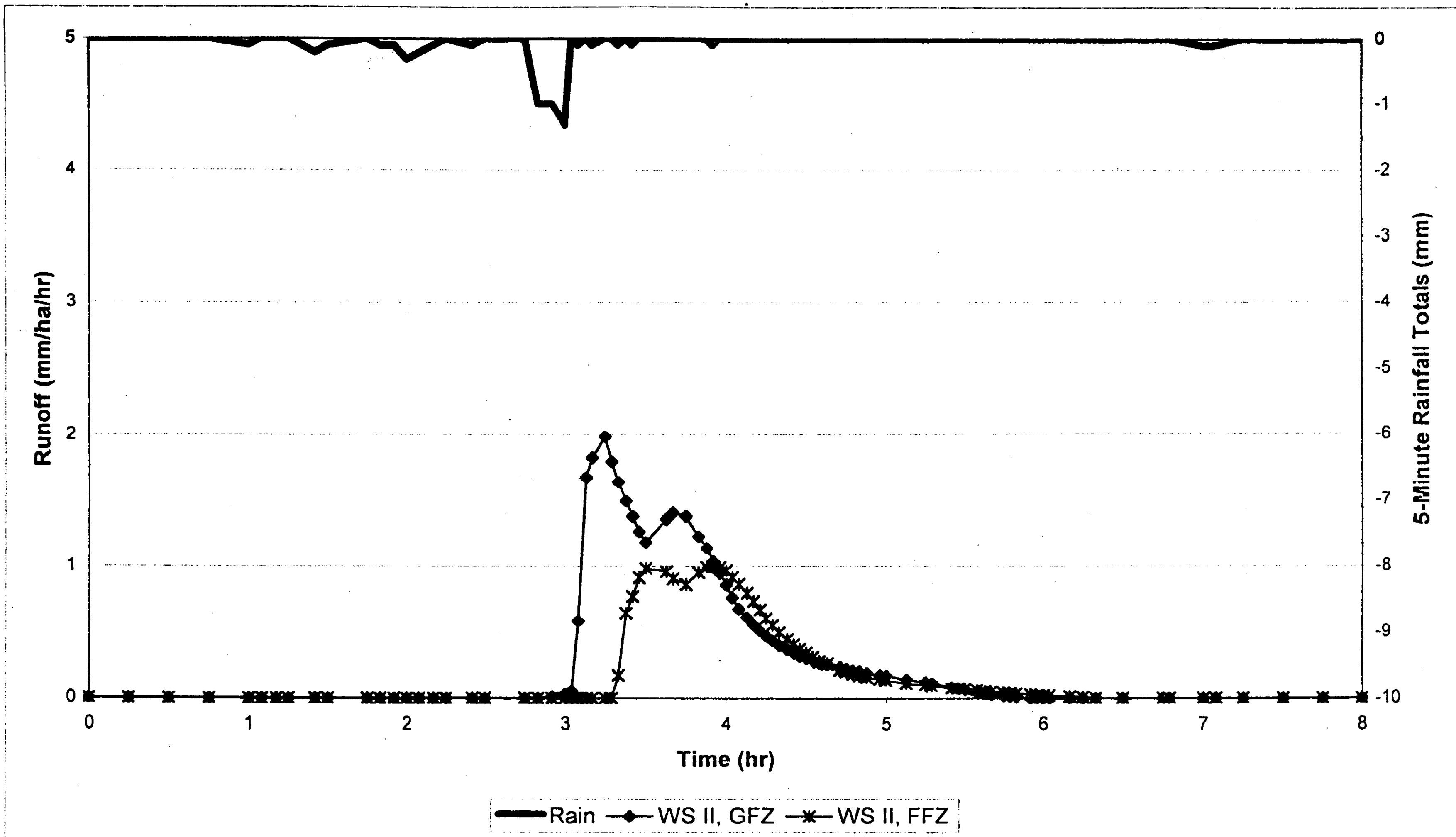
Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 244, 2000. Event 1.



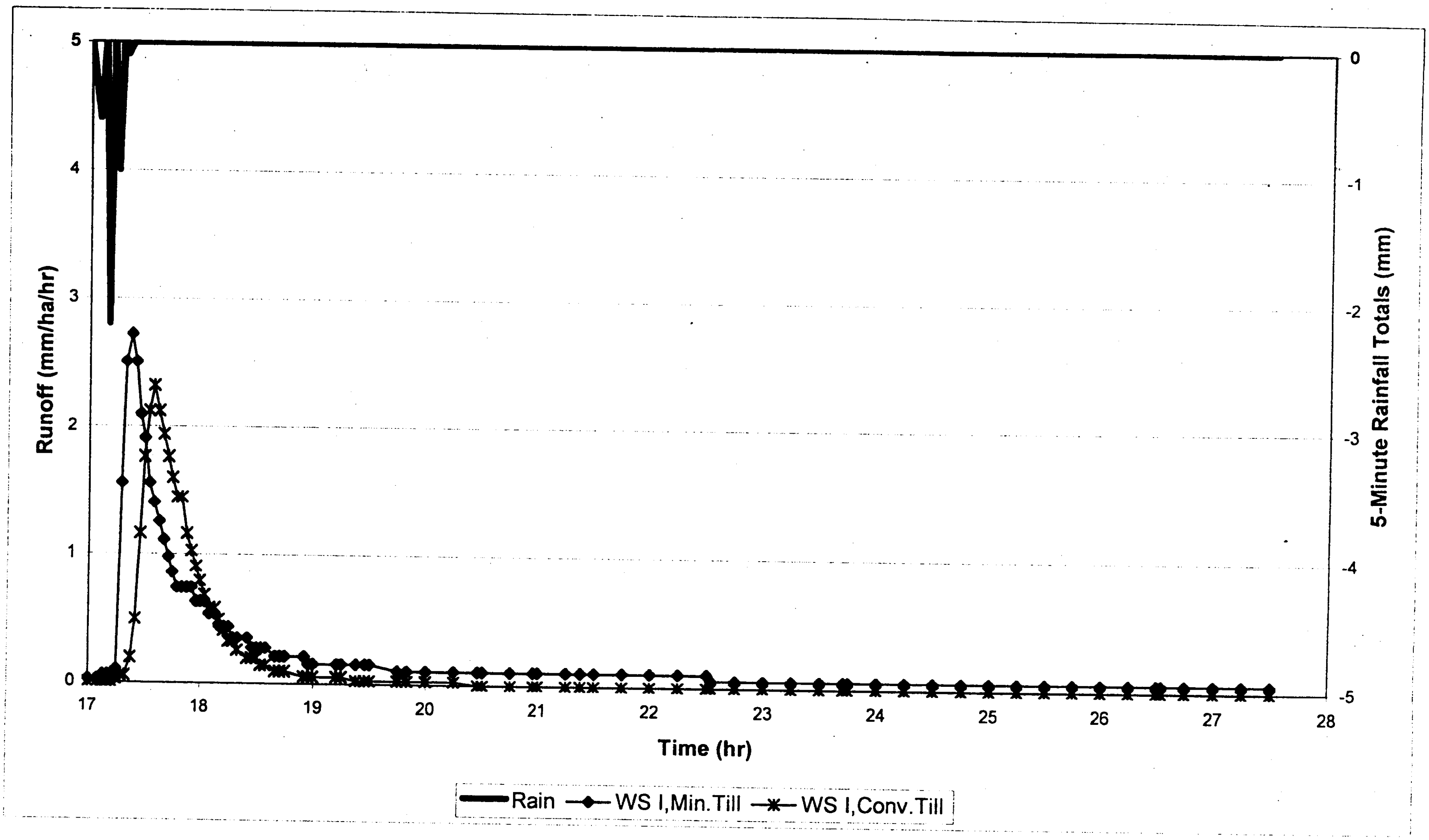
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 244, 2000. Event 1.



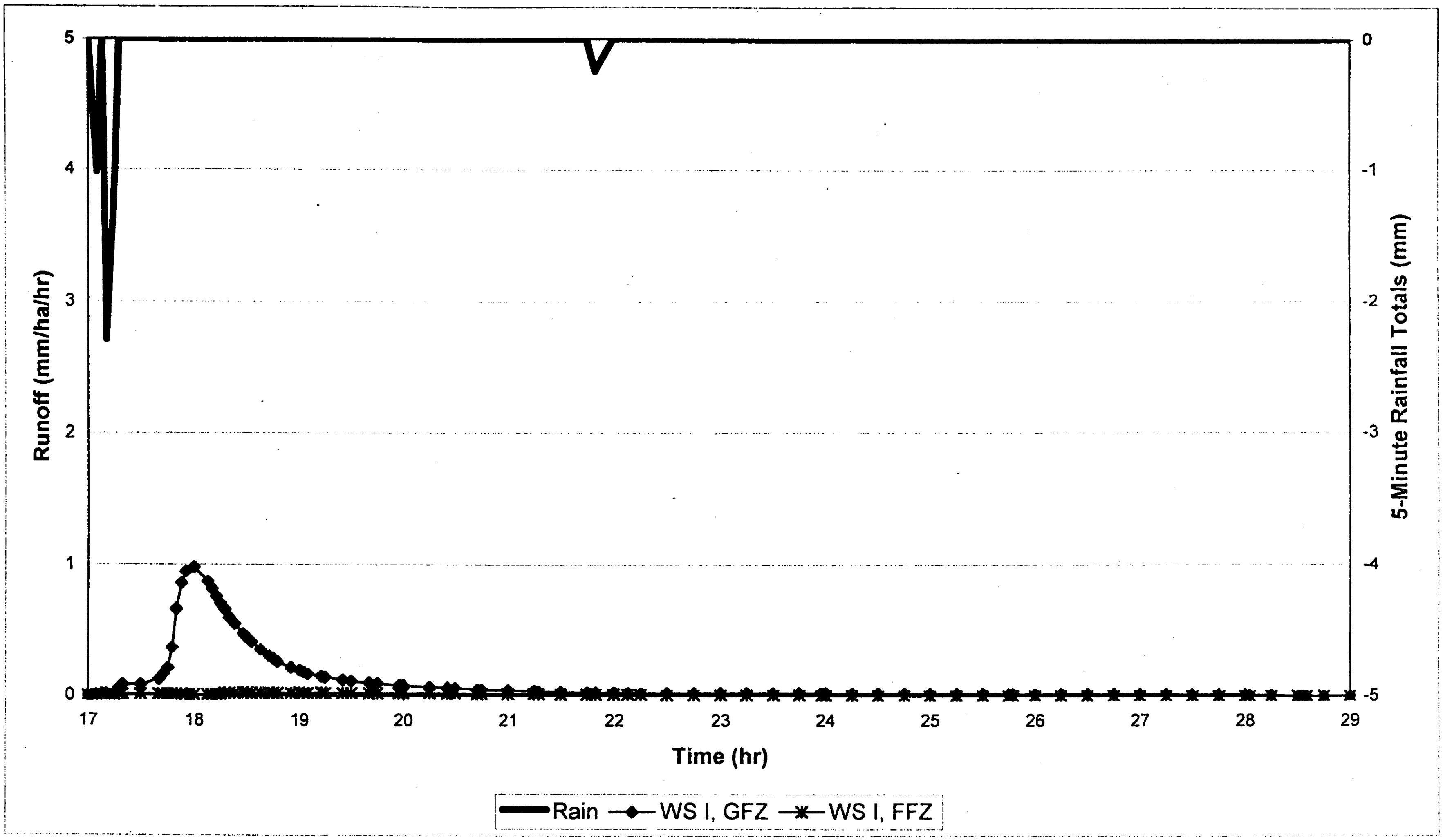
Storm Hydrograph for Oxford Tobacco Fields, Watershed II. Julian Day 244, 2000. Event 1.



Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 244, 2000. Event 1.



Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 244, 2000. Event 2.



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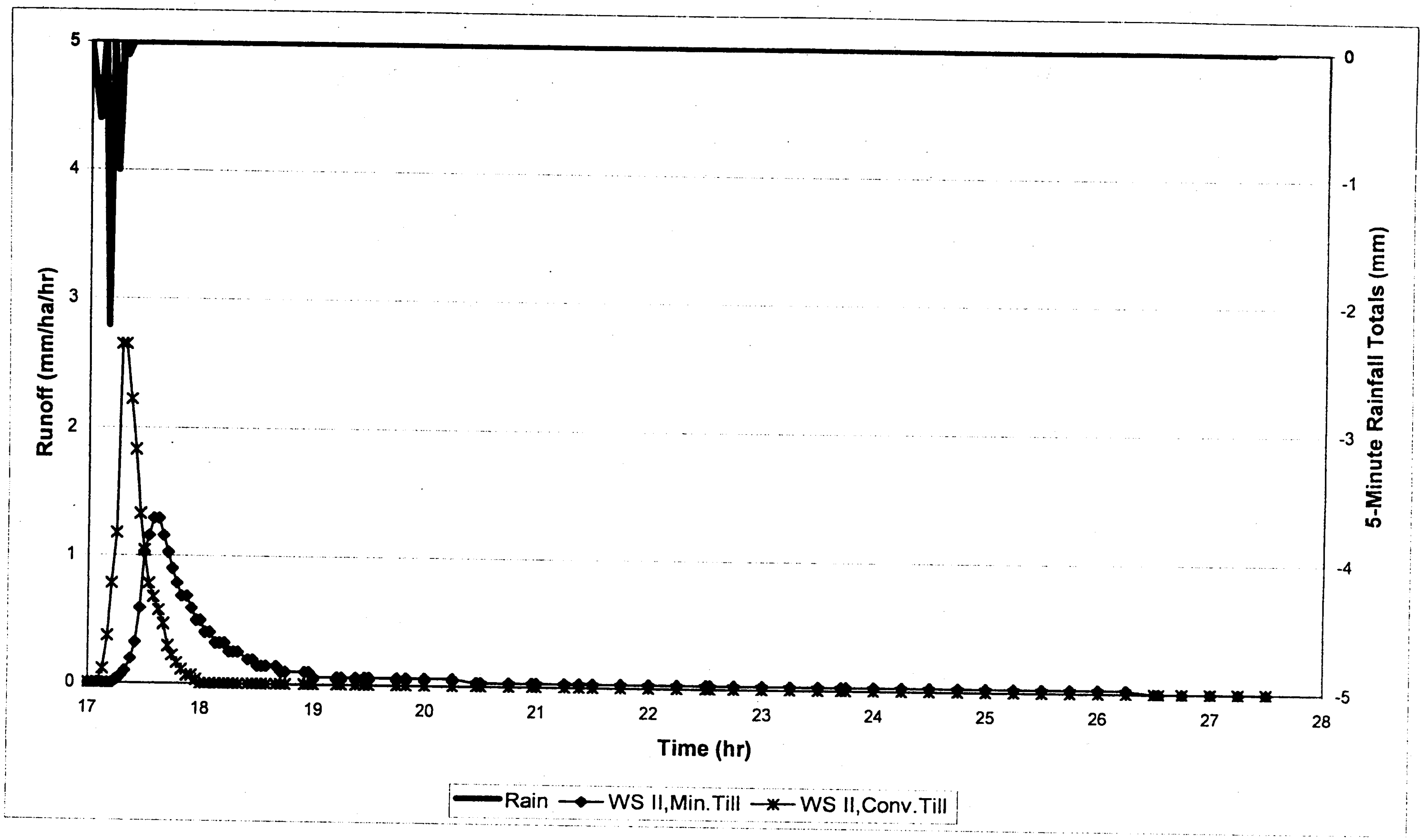

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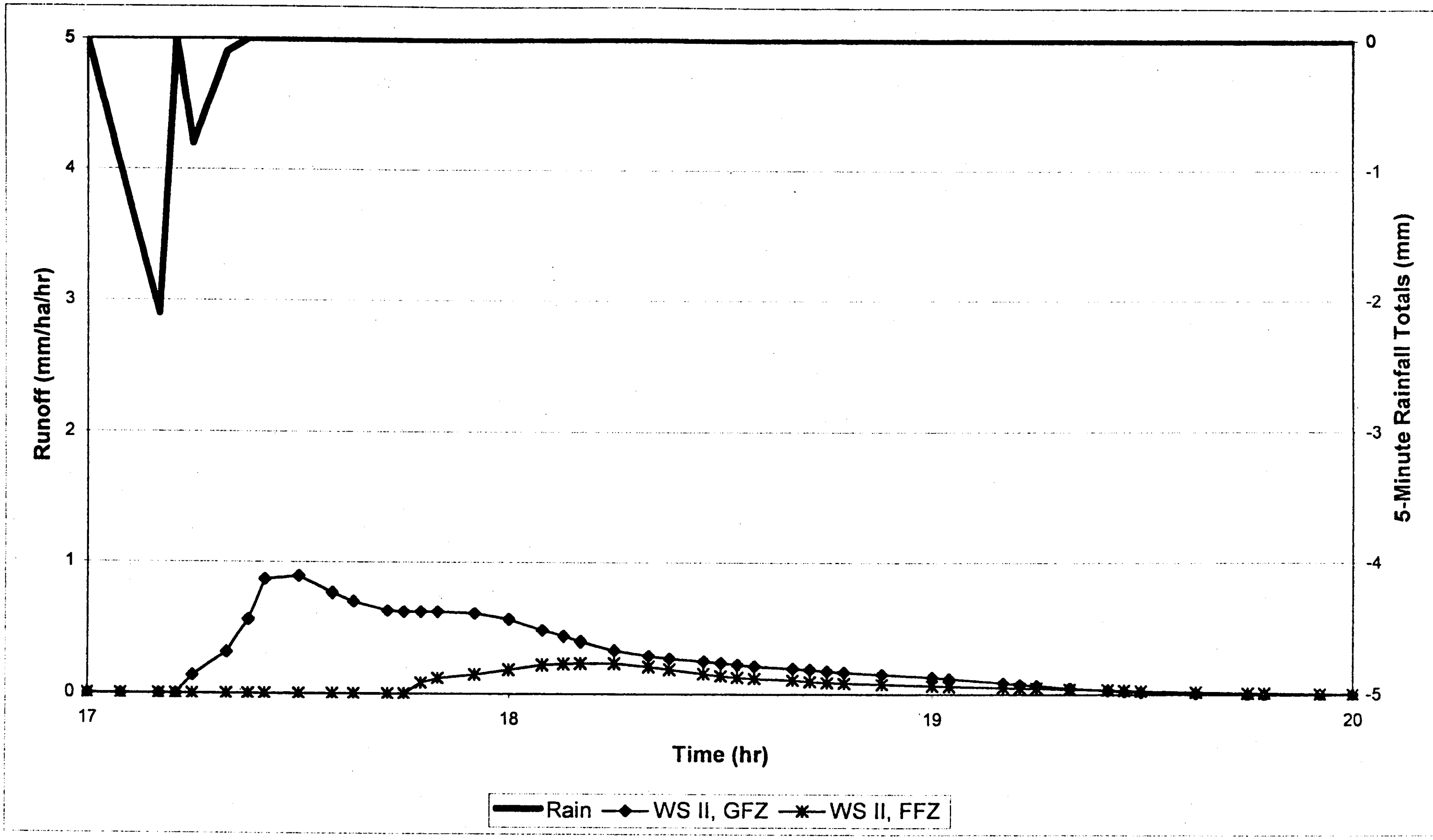
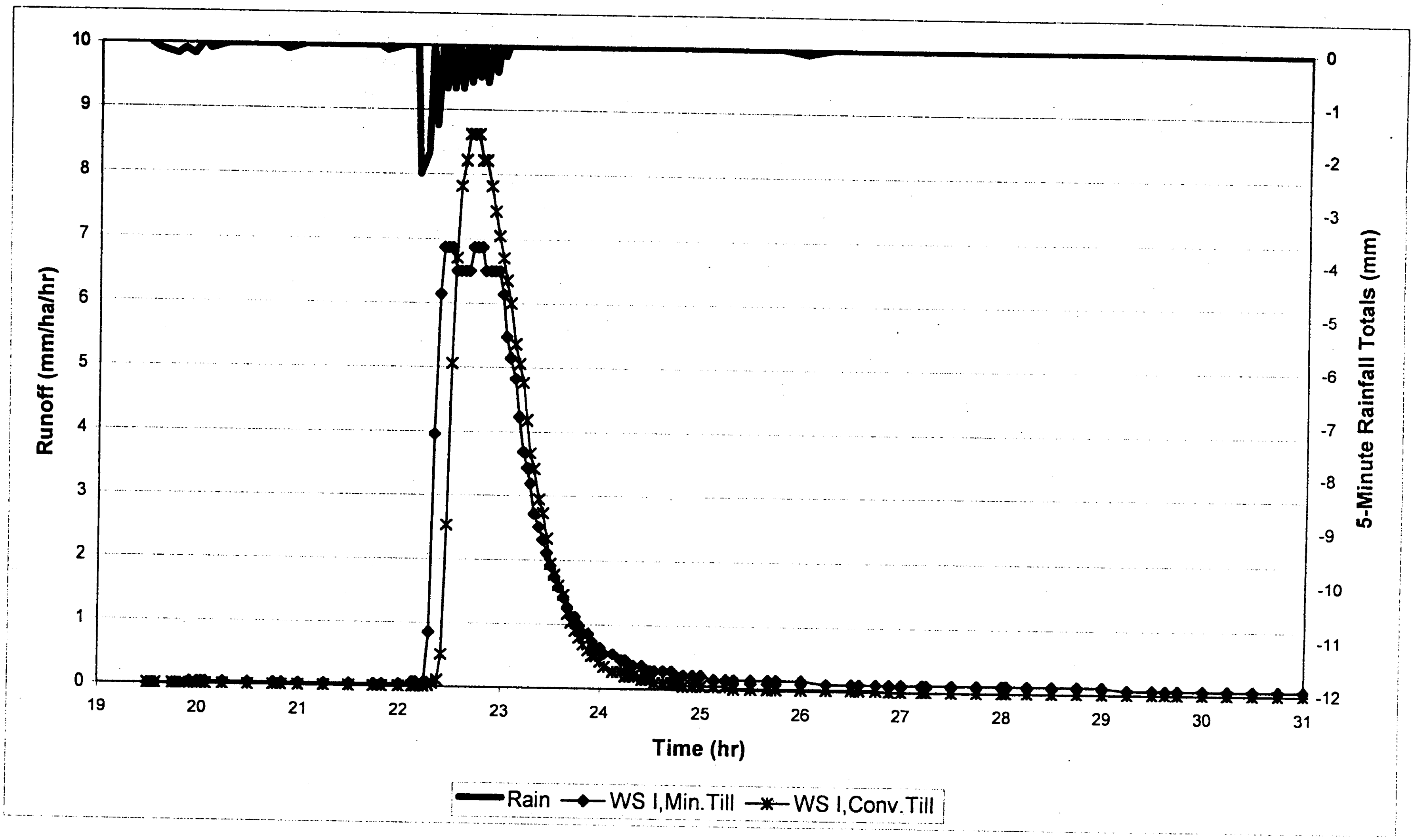
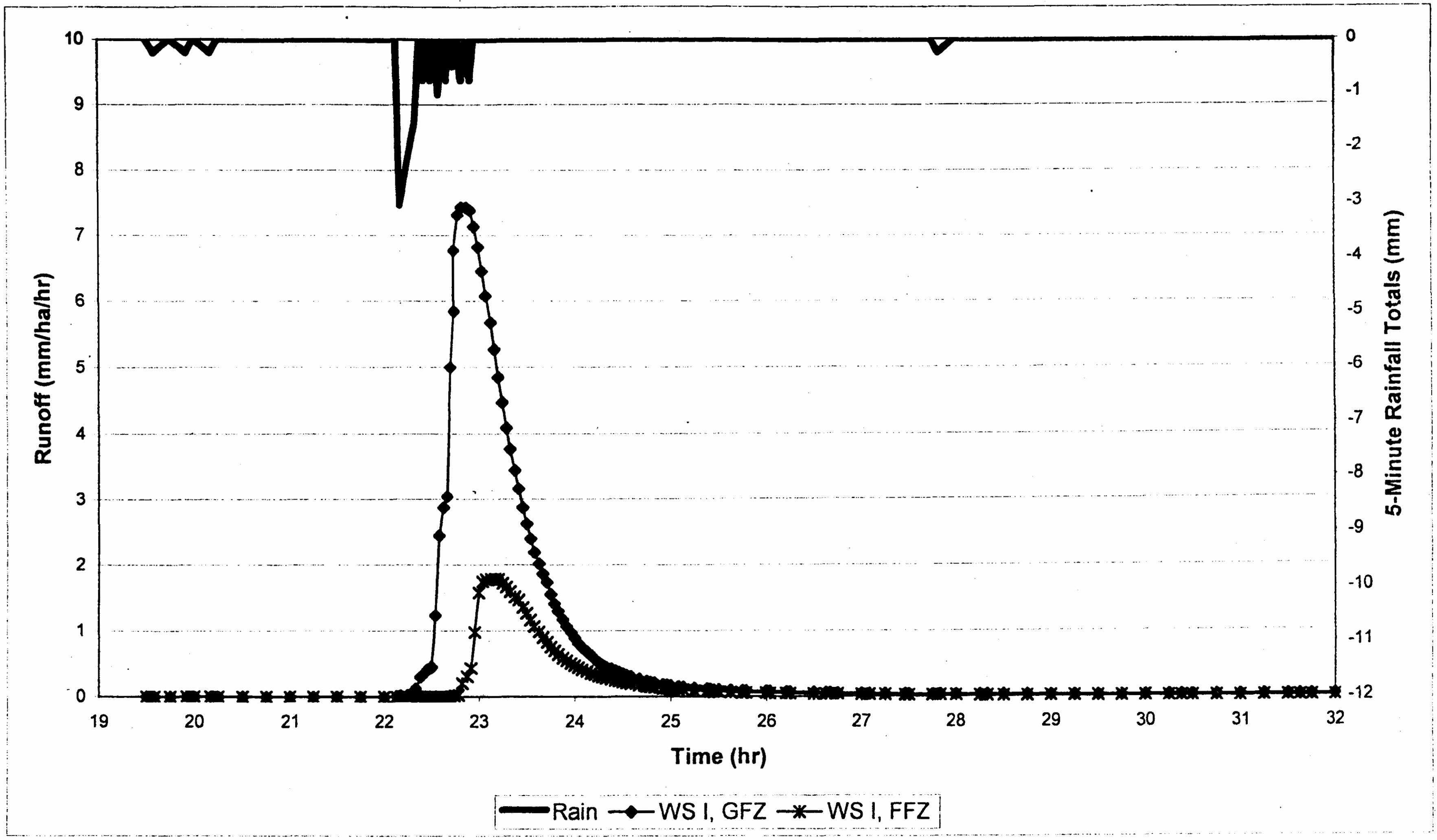


Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 244, 2000. Event 2.



Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 246, 2000.



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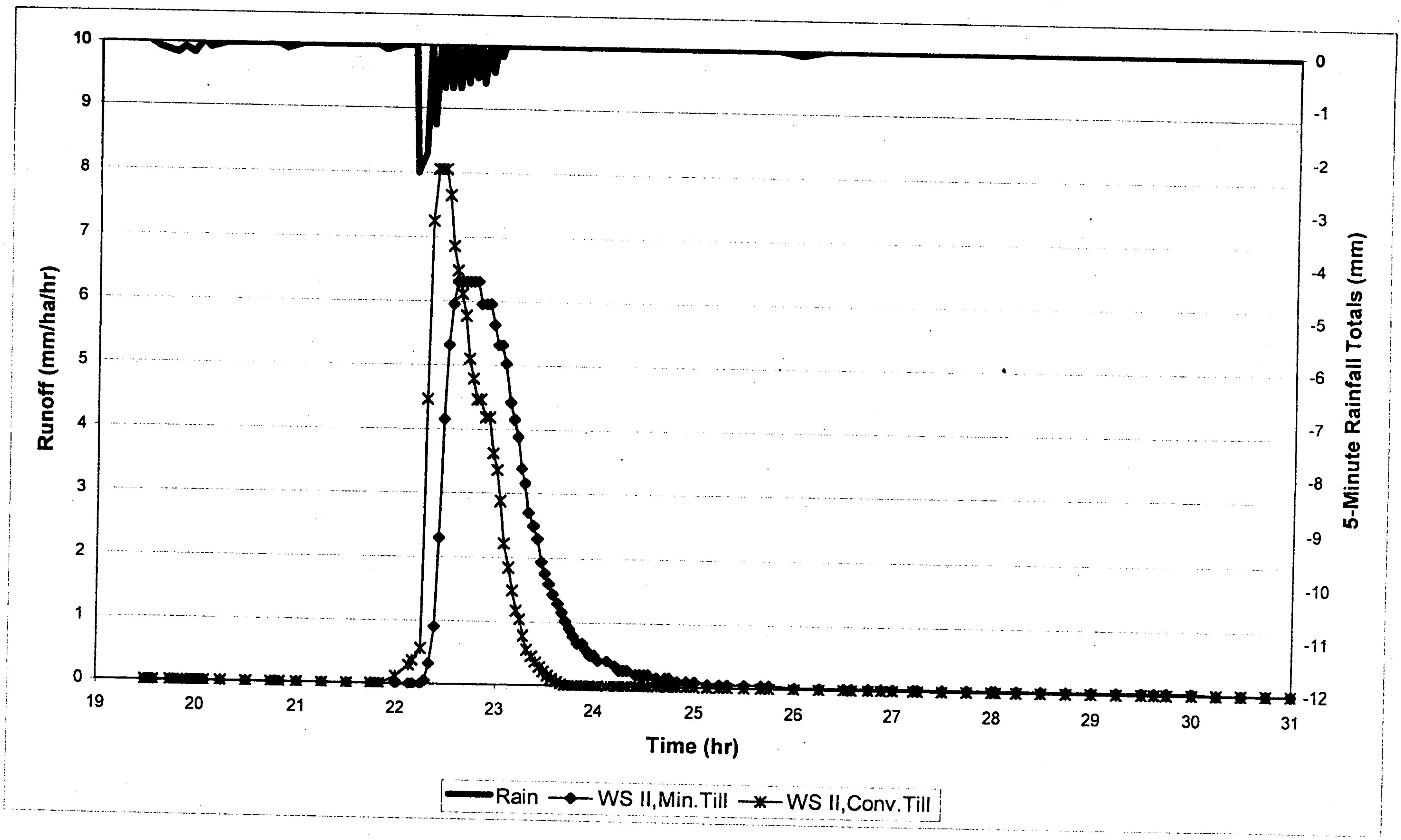

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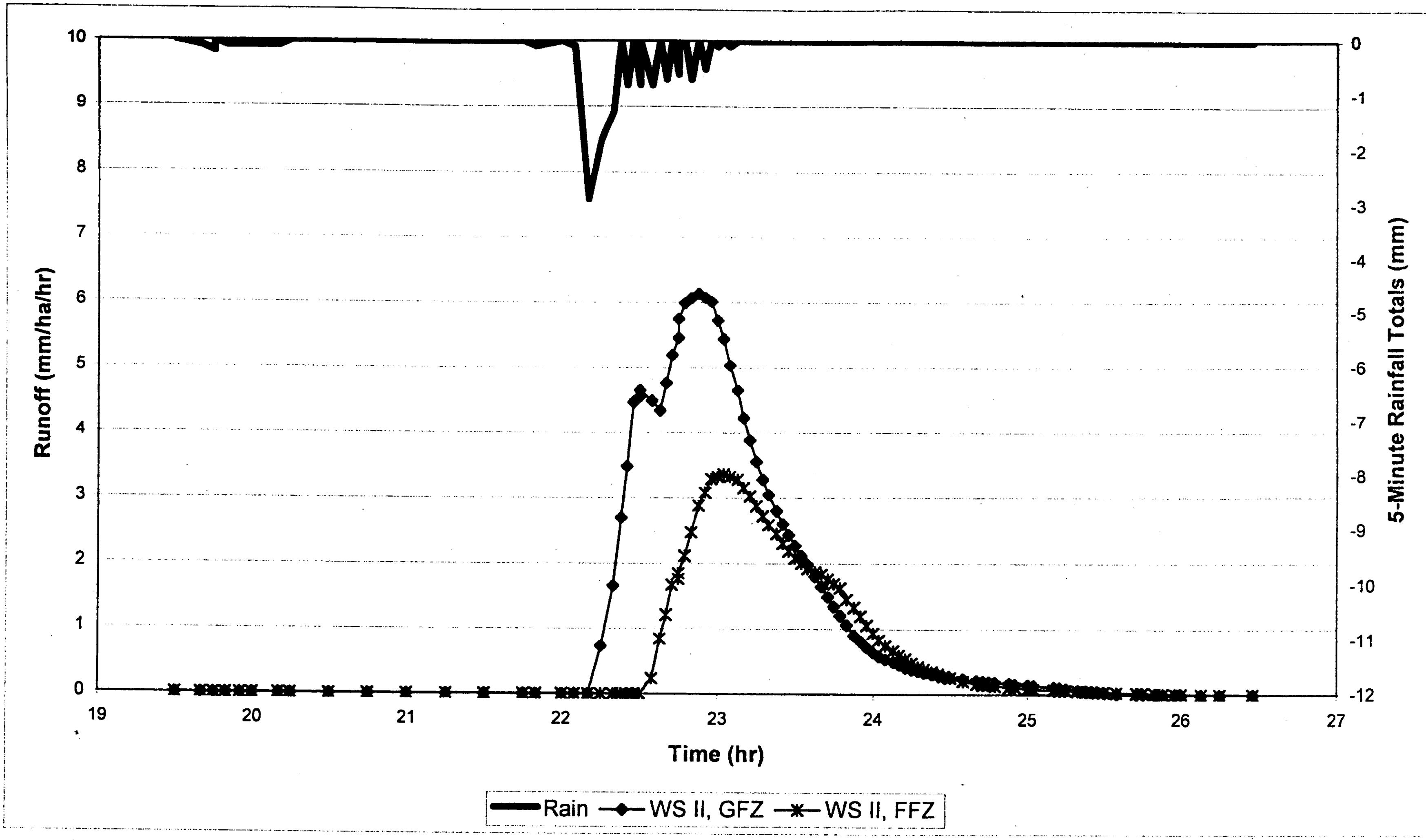
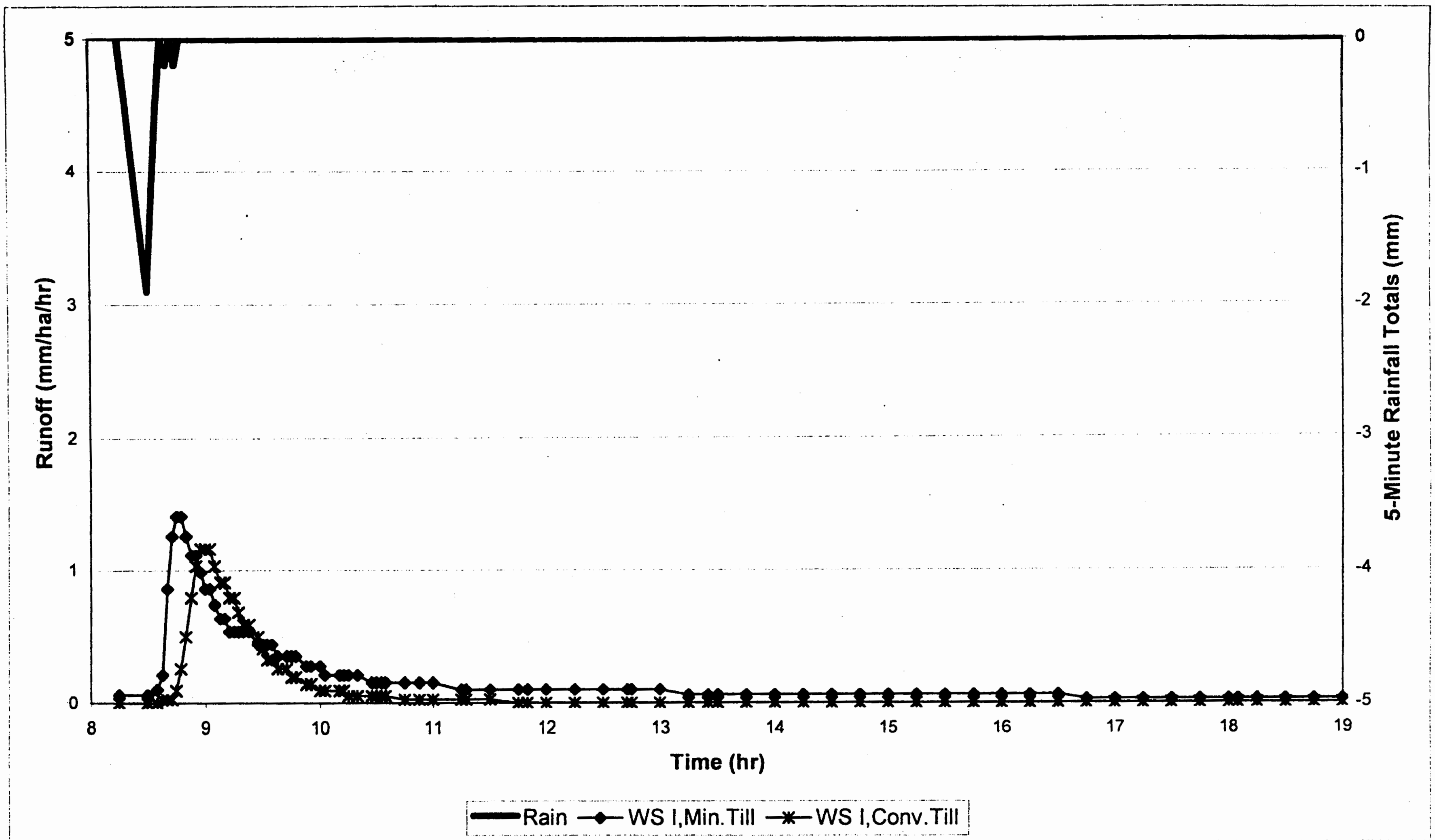
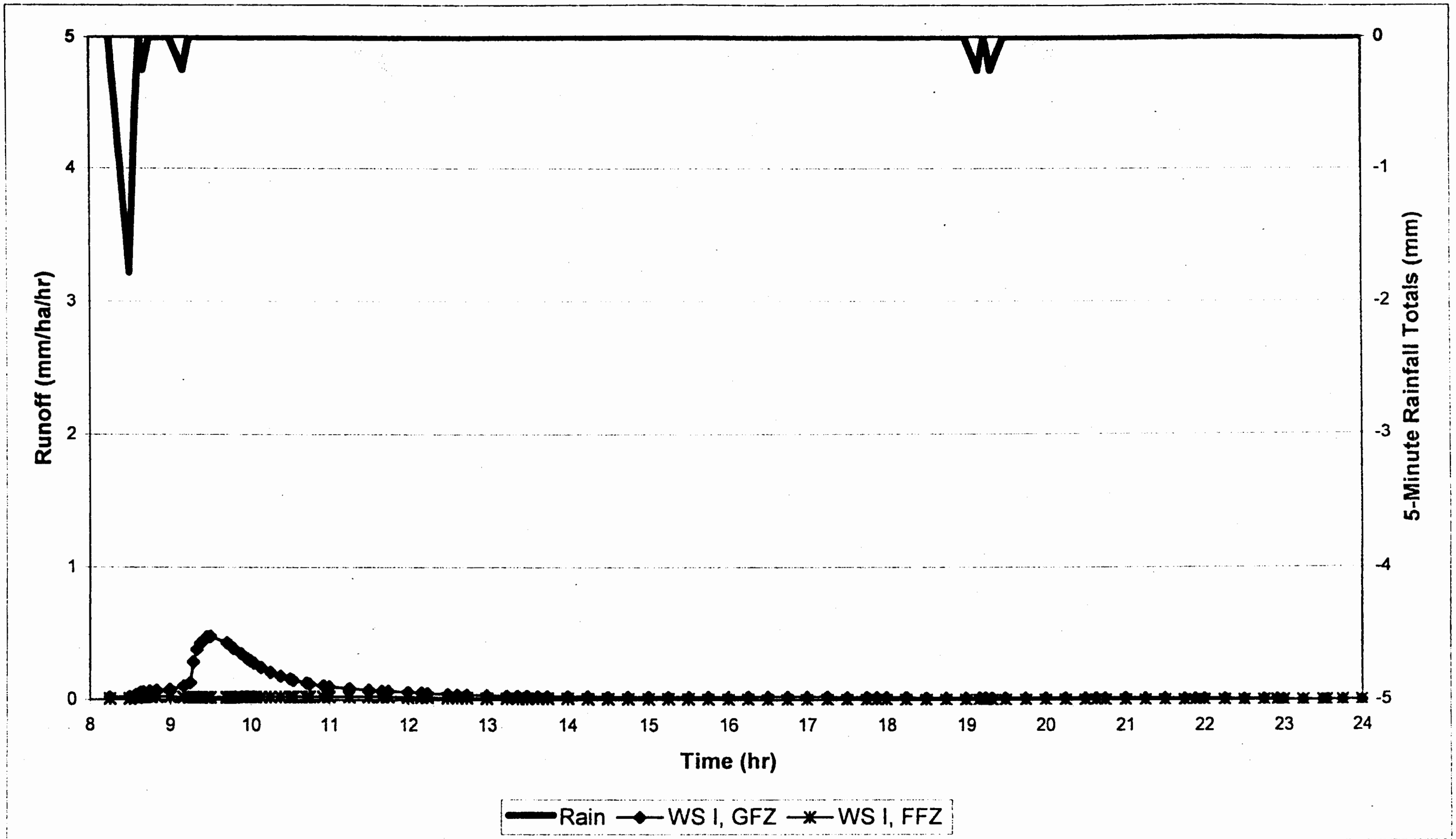


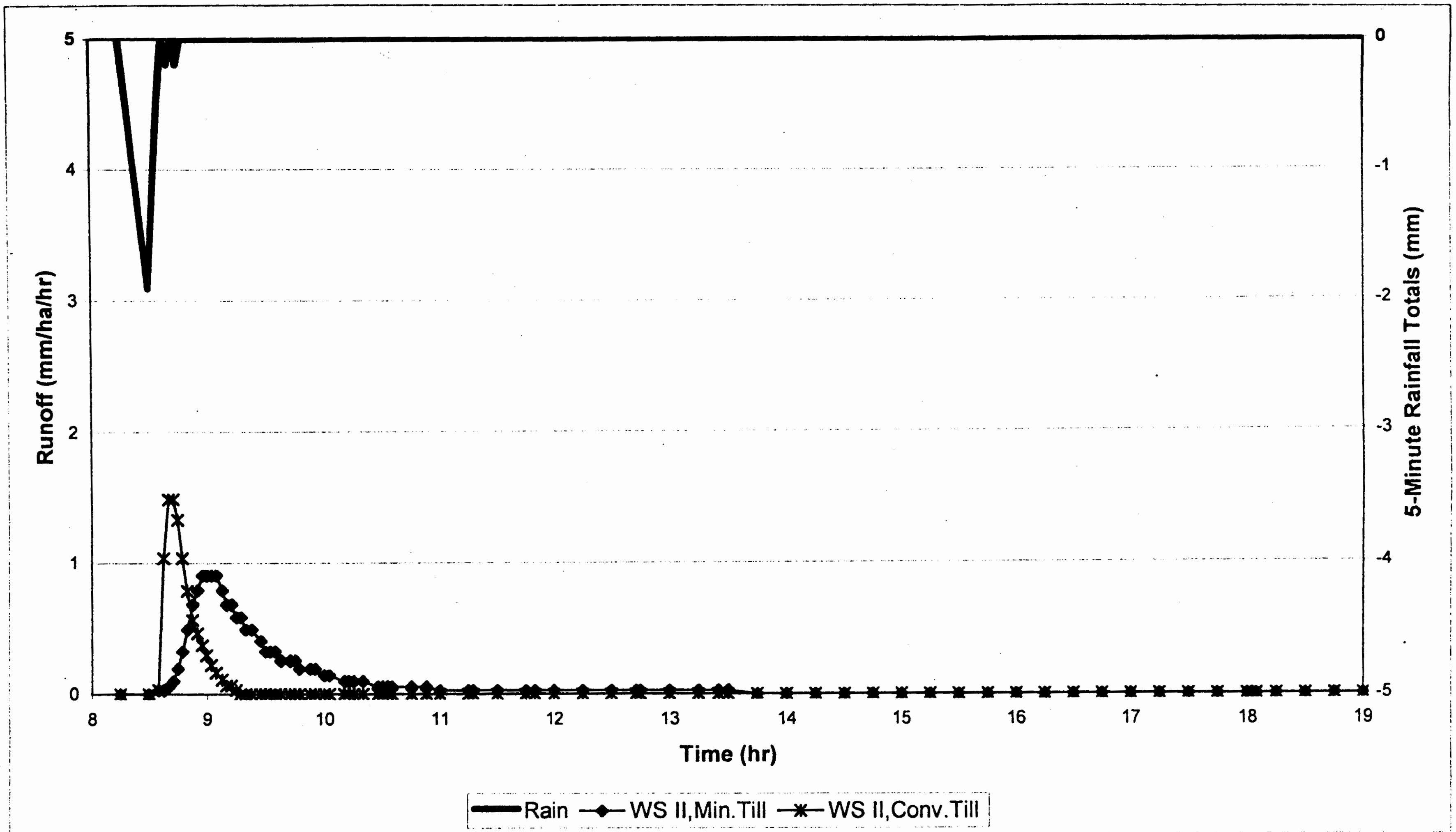
Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 246, 2000.



Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 247, 2000.



Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 247, 2000.



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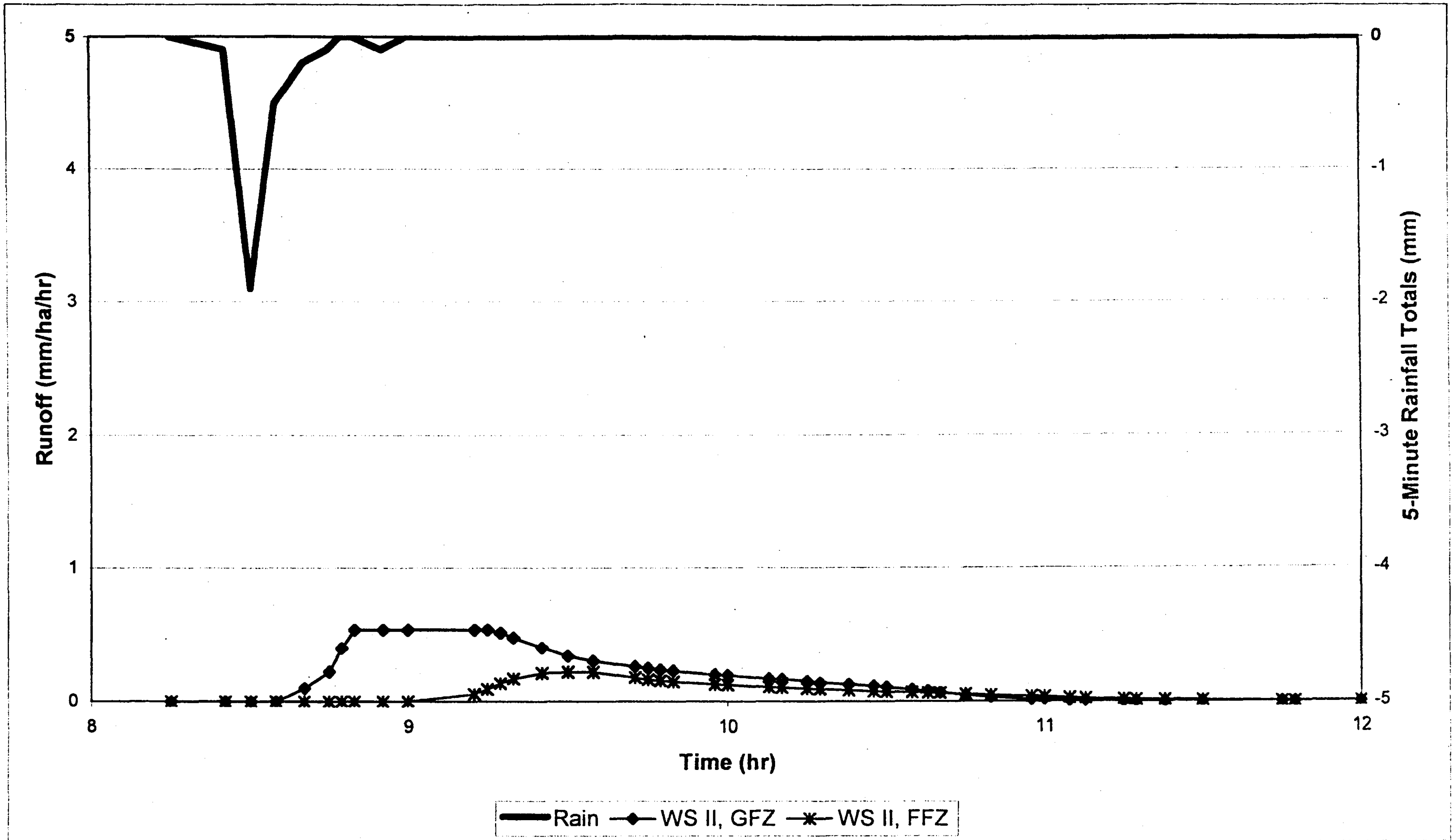
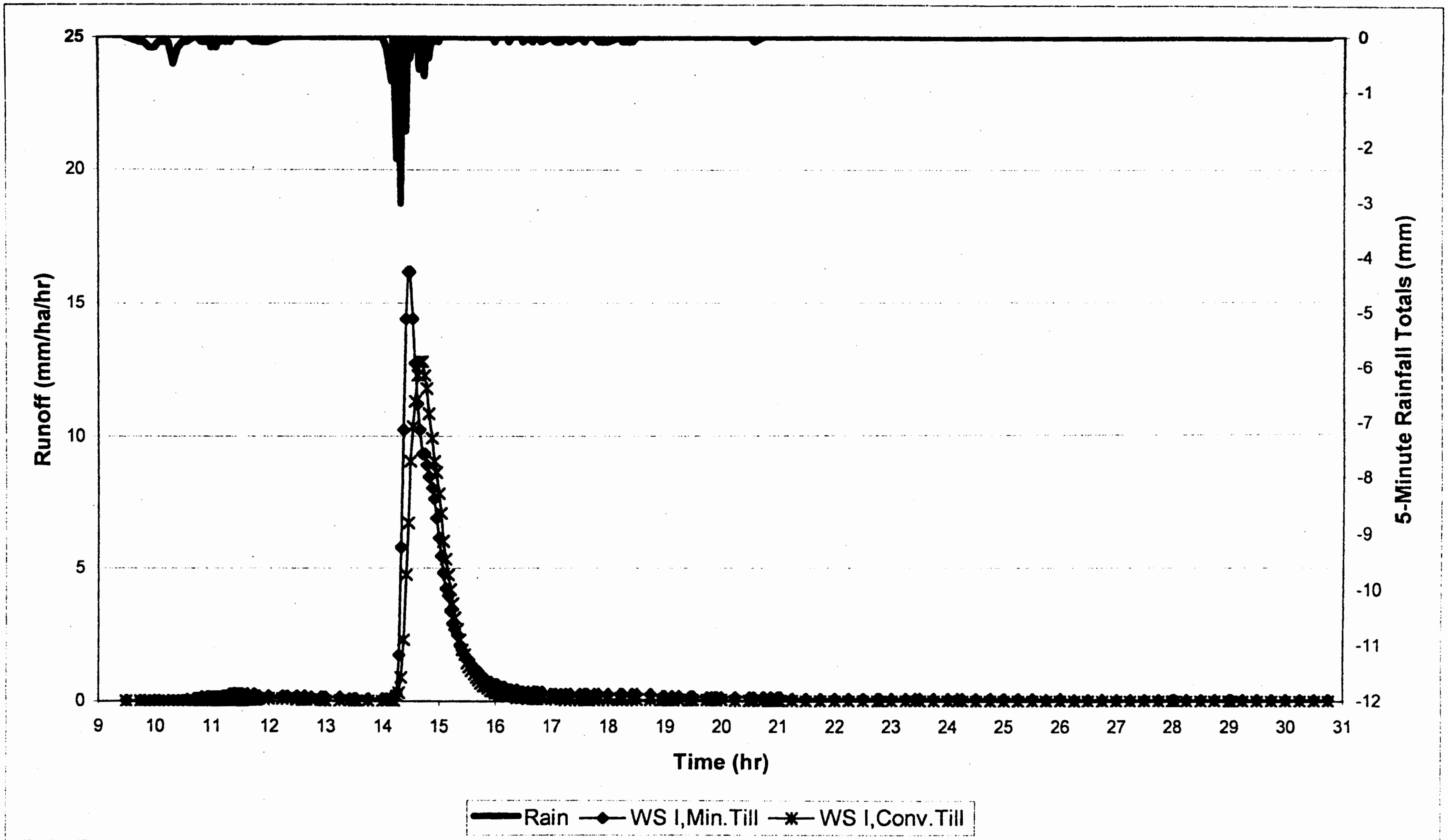


Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 247, 2000.



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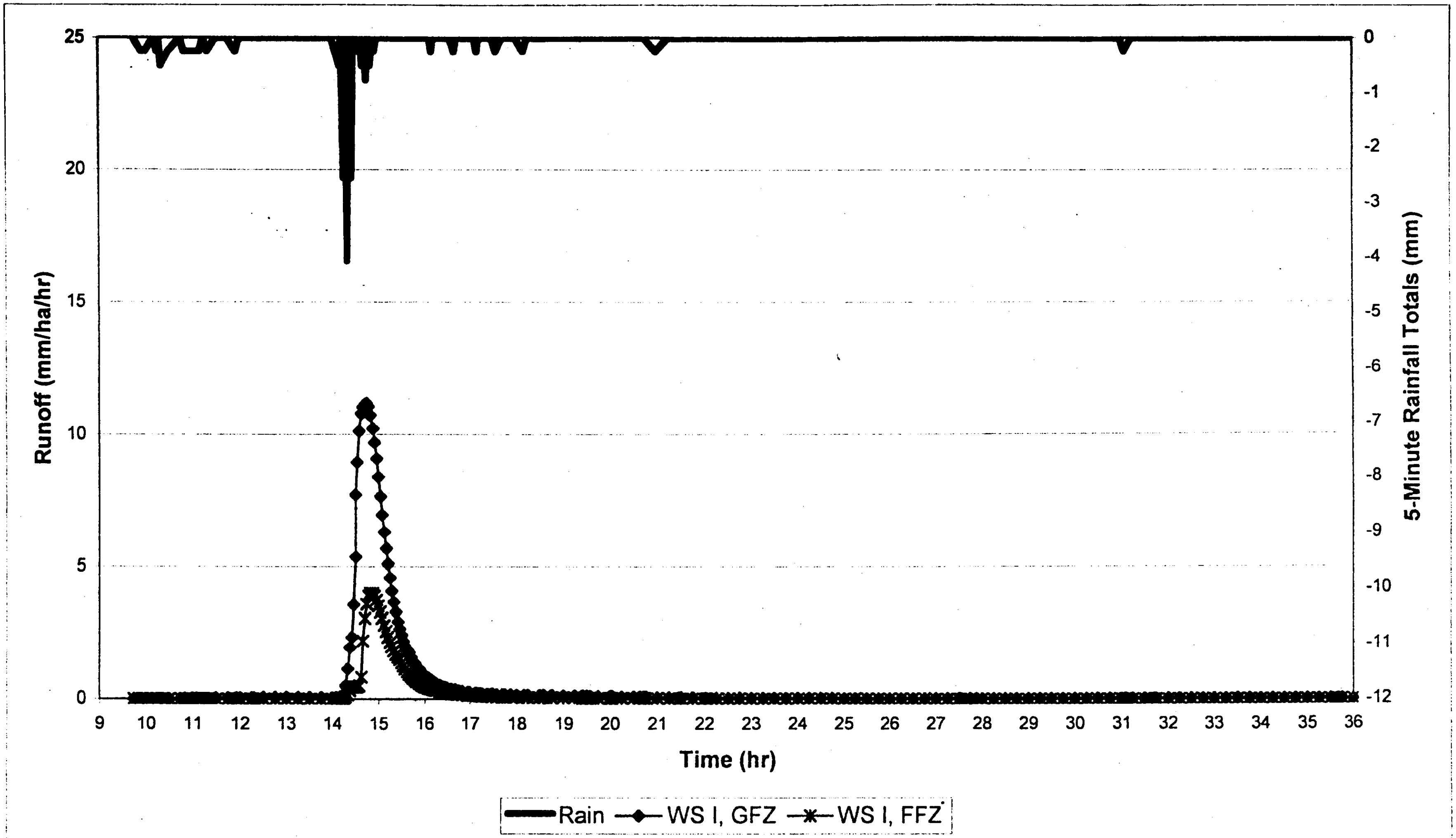
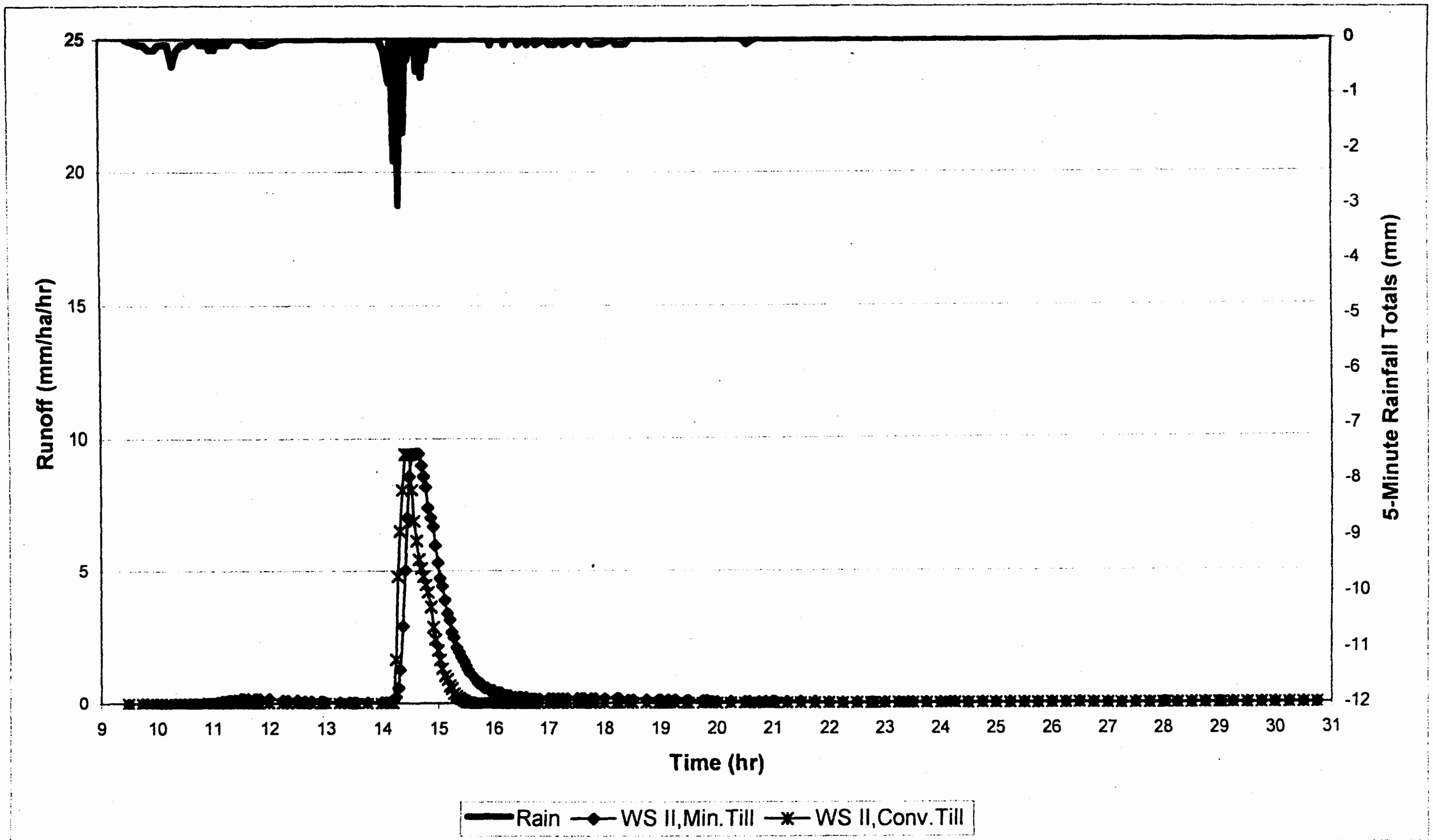


Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed I. Julian Day 248, 2000.



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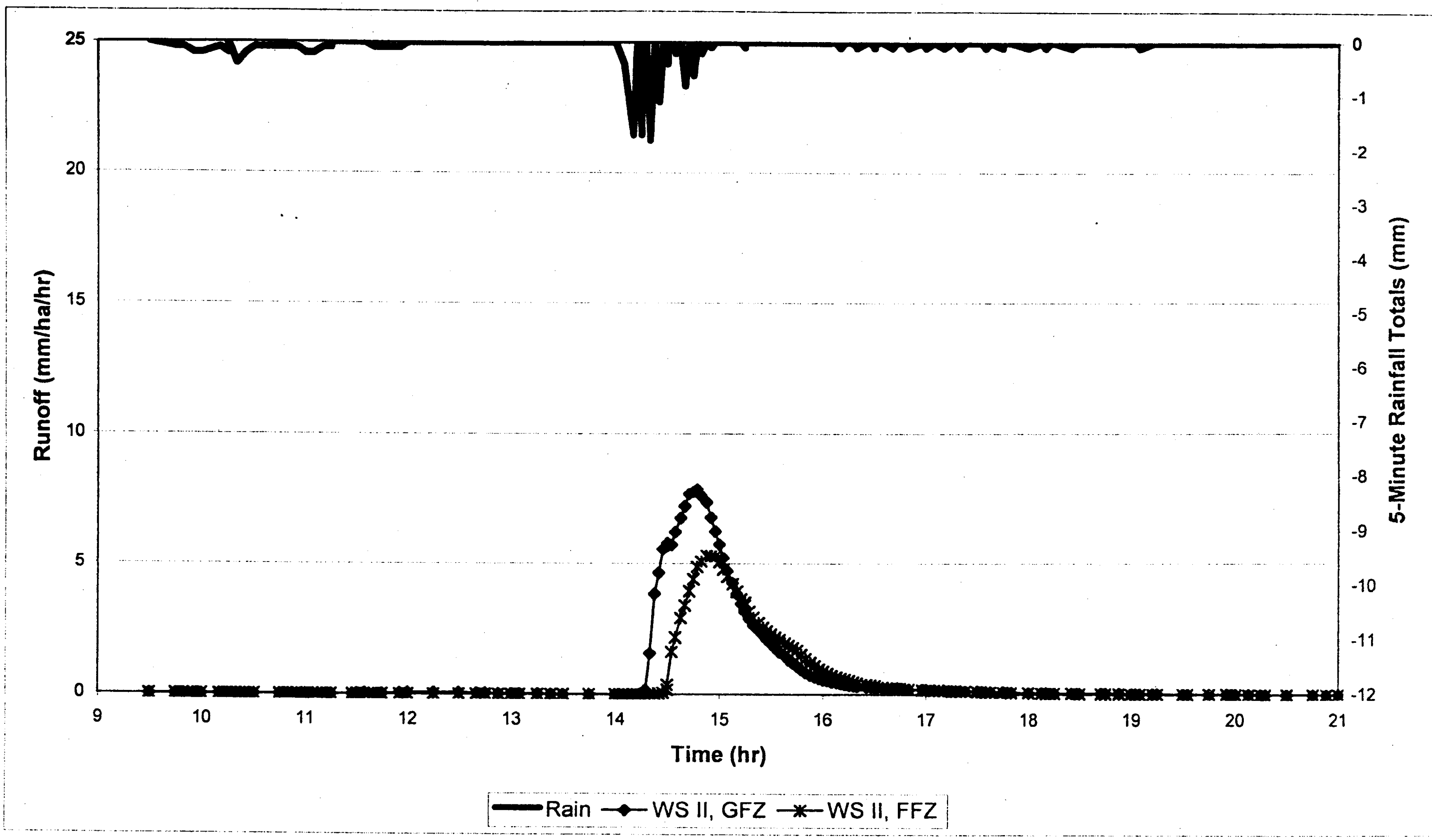
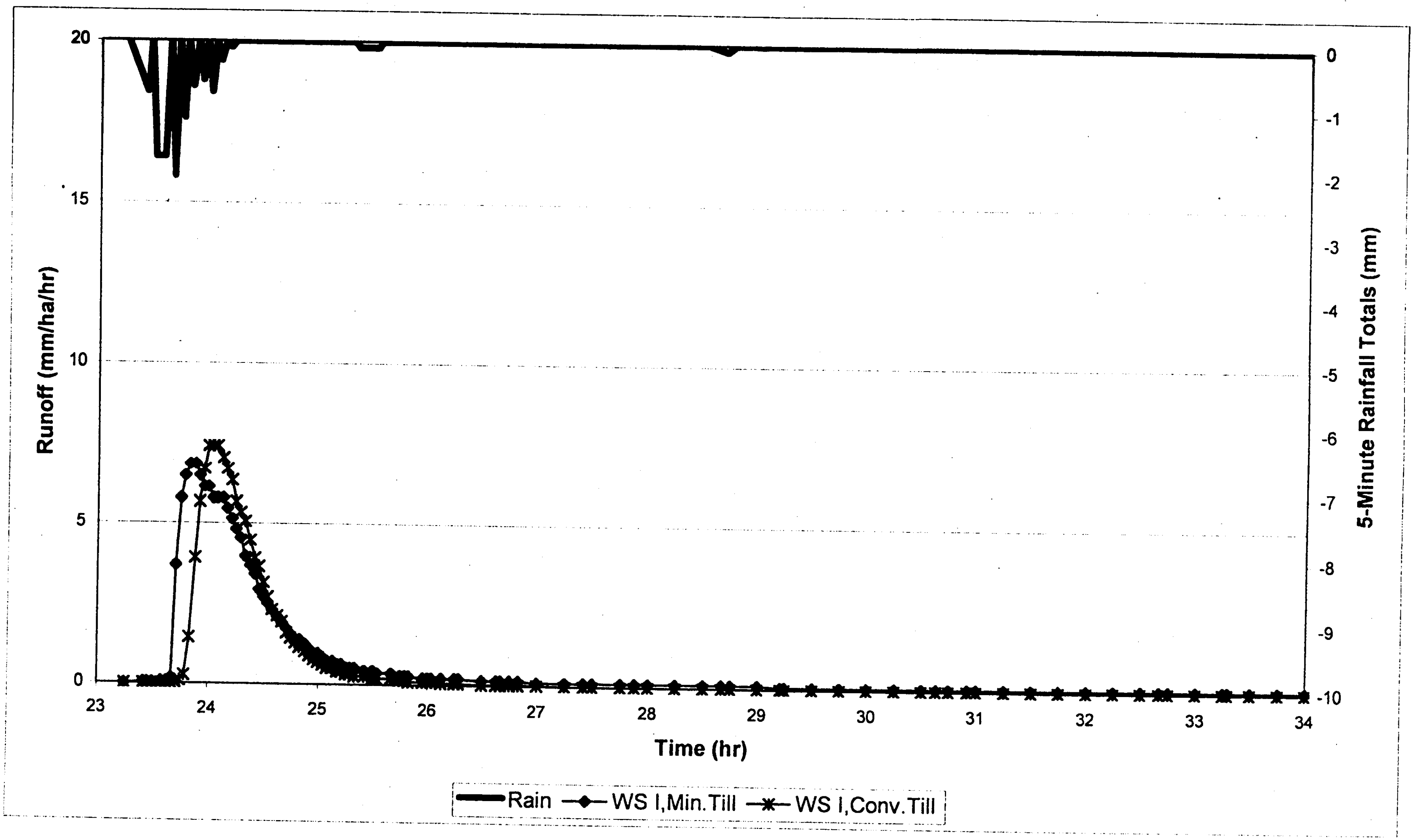
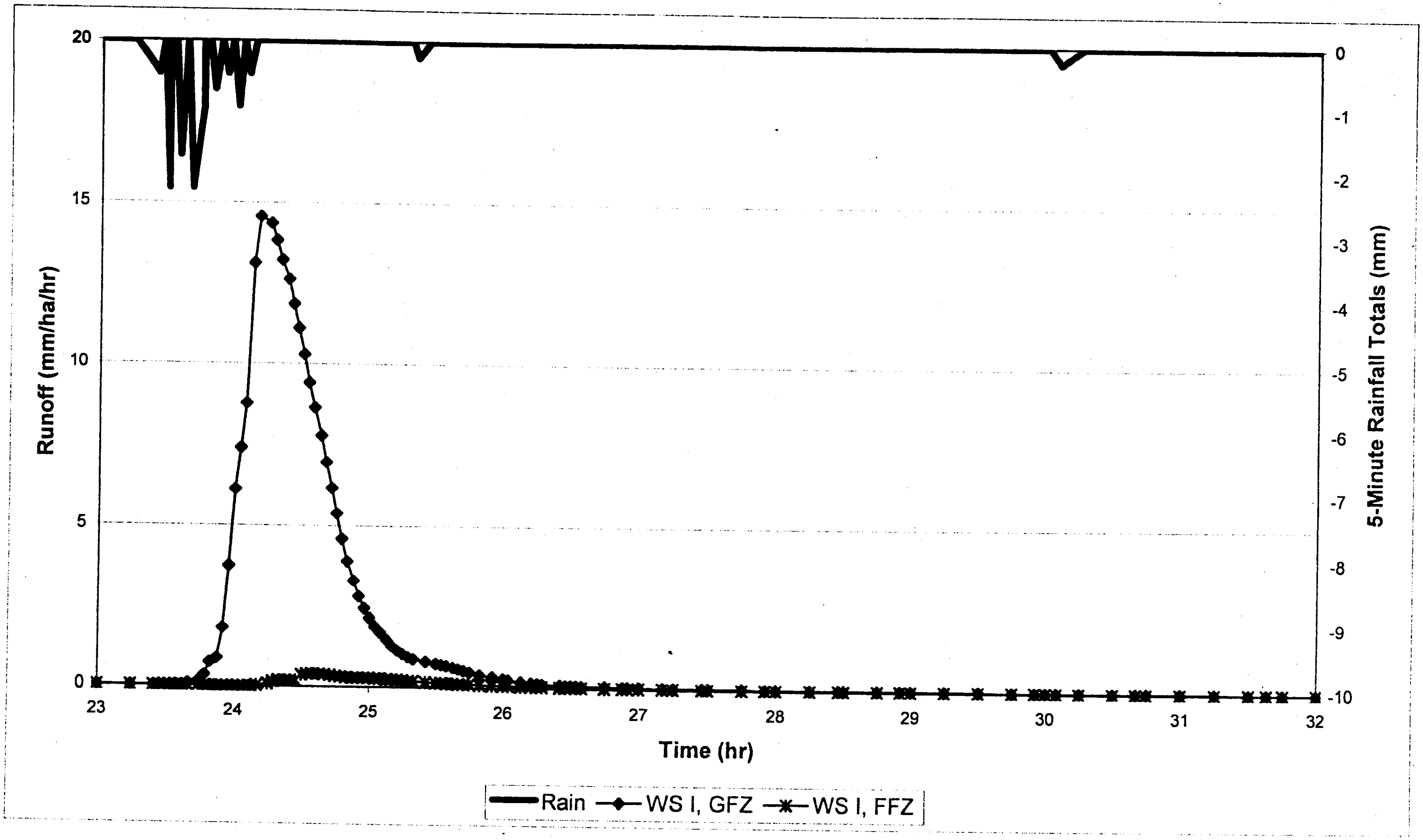


Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 248, 2000.



Storm Hydrograph for Oxford Tobacco Fields, Watershed I. Julian Day 268, 2000.



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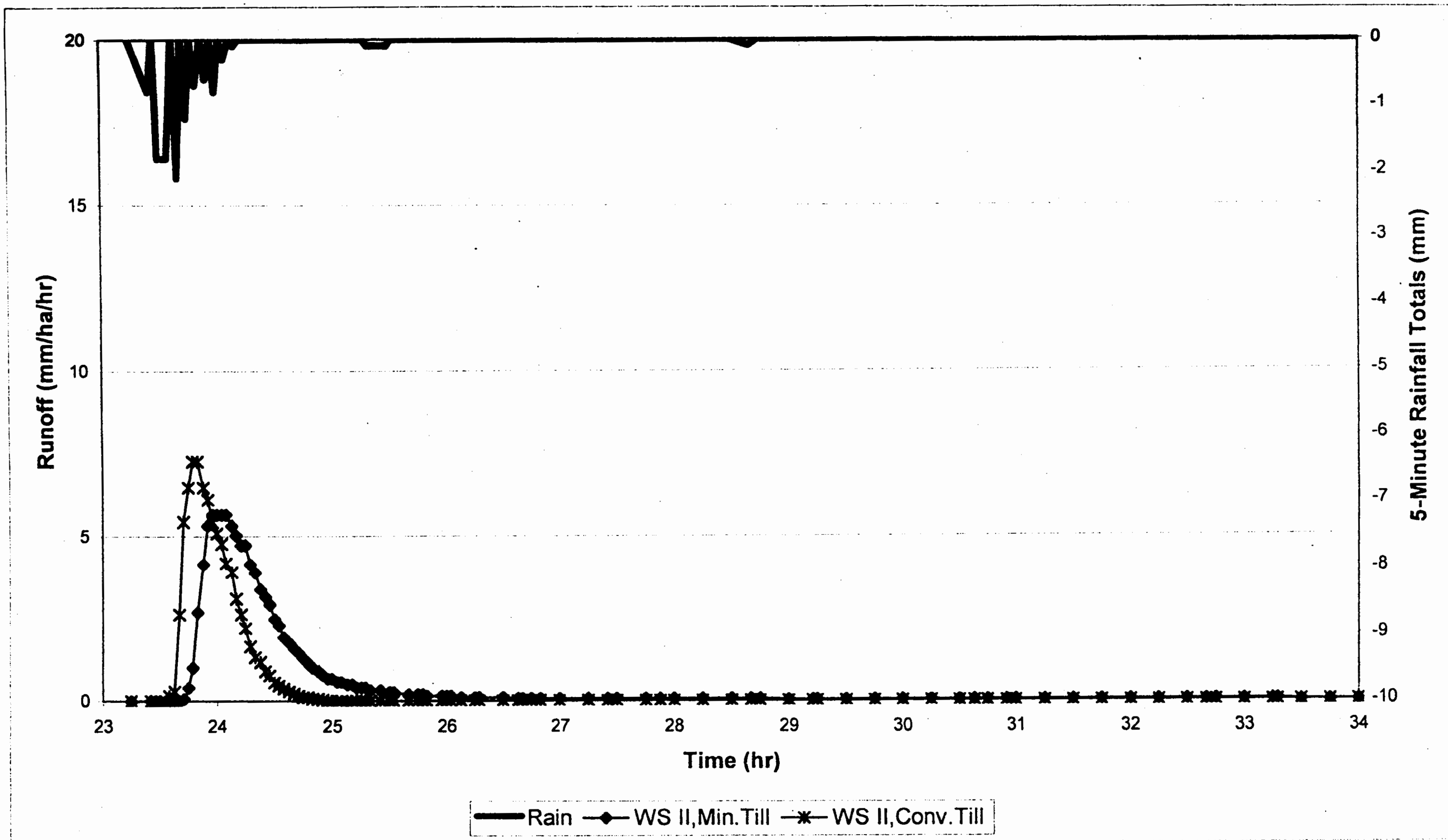

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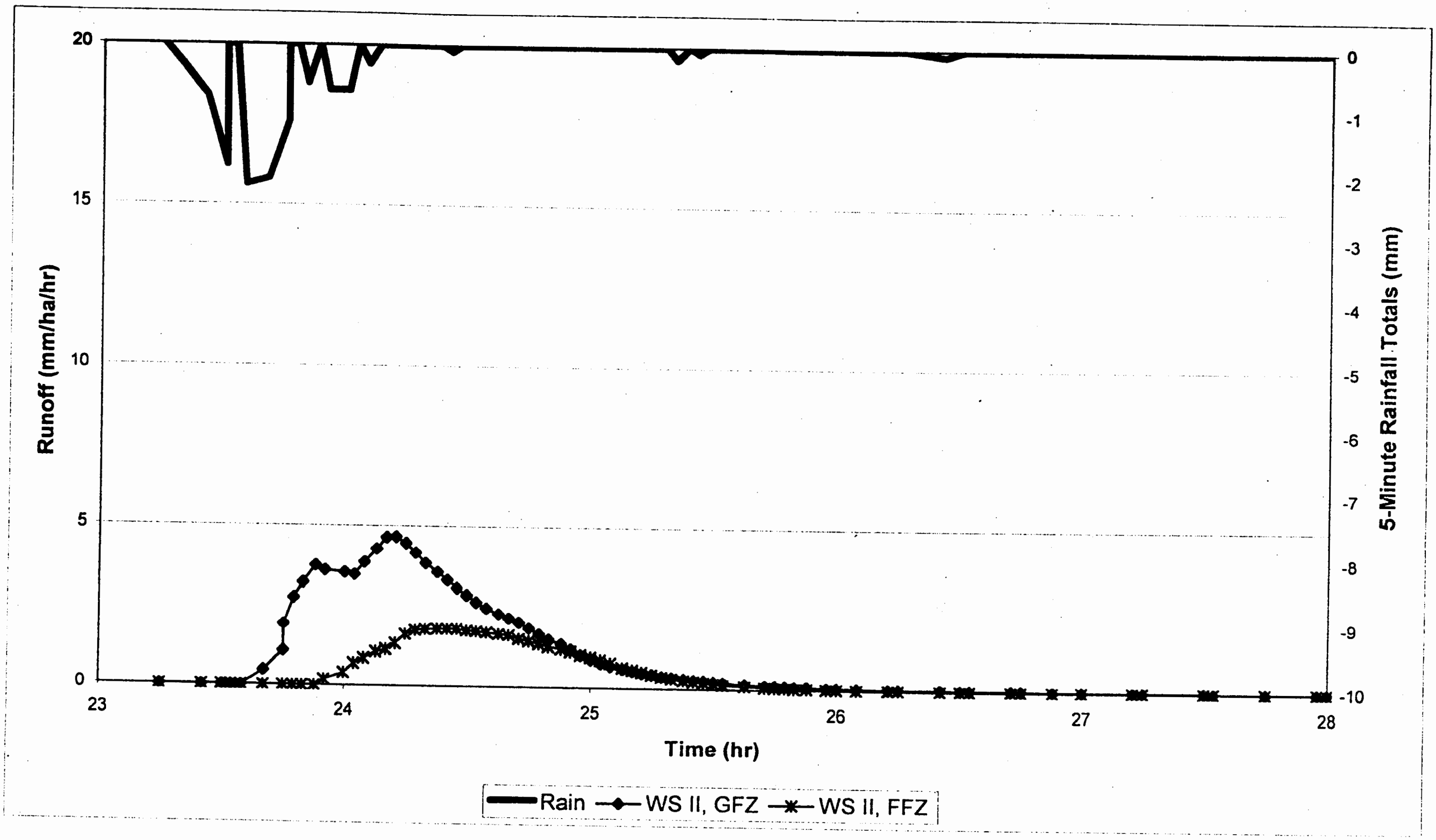

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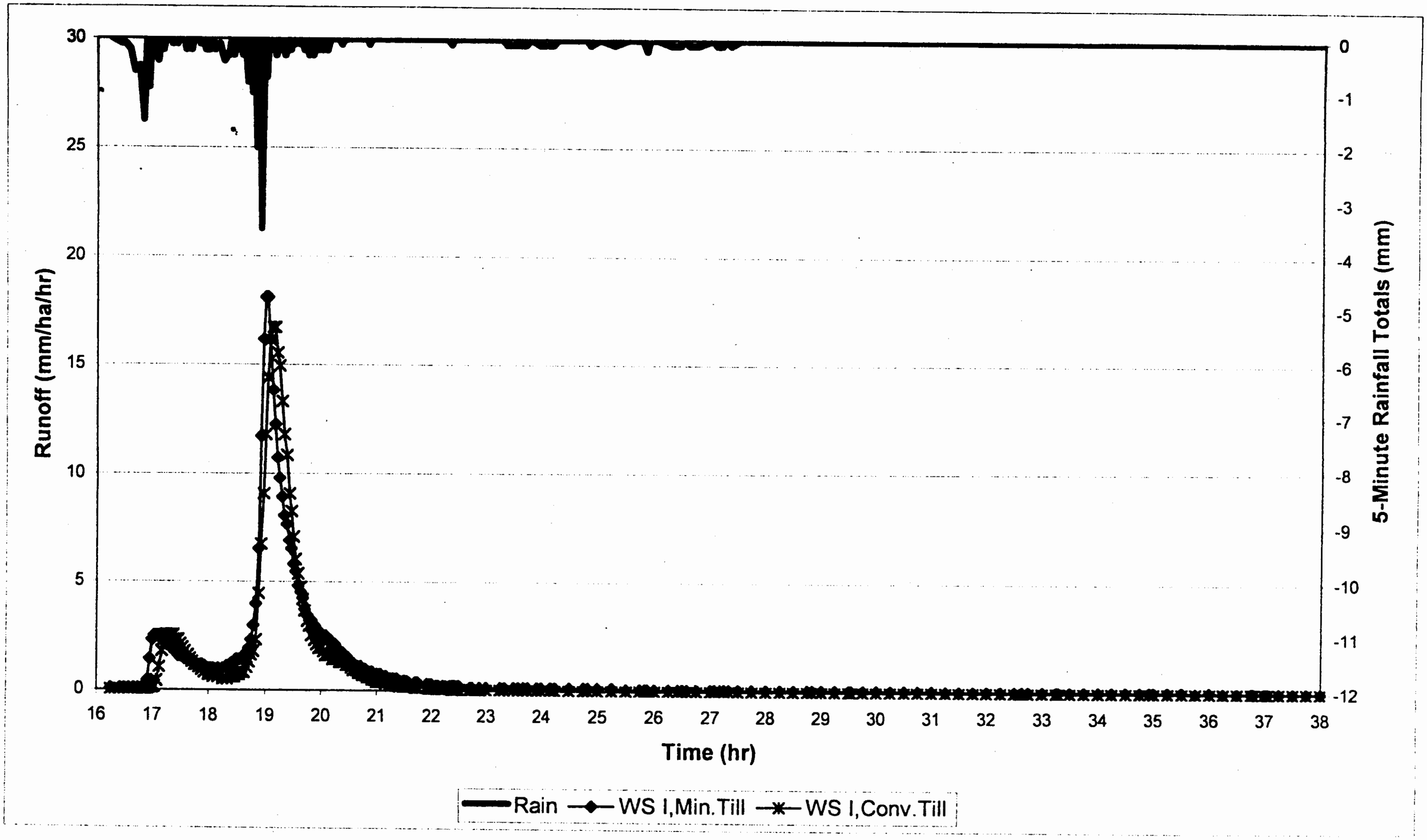

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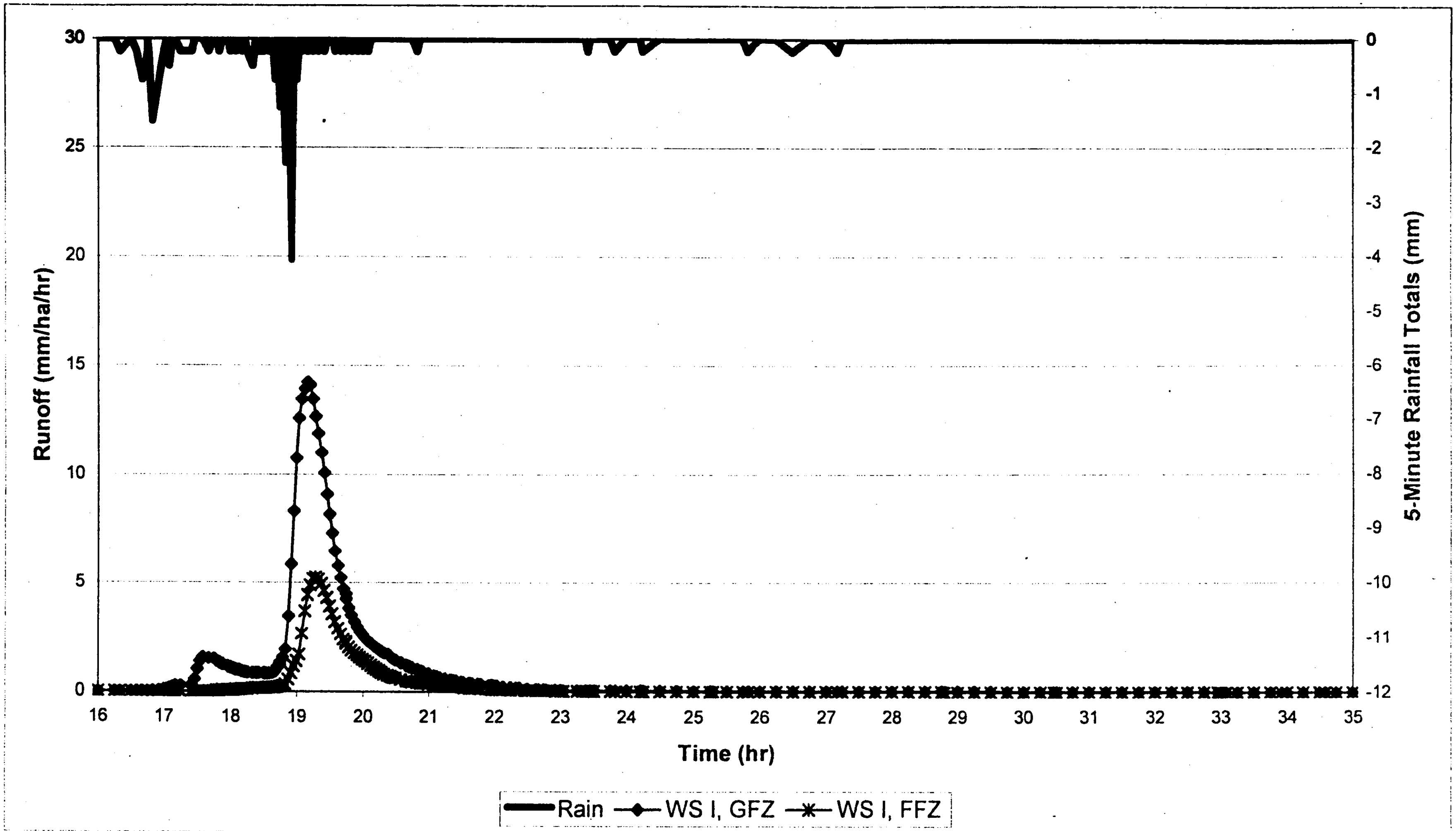

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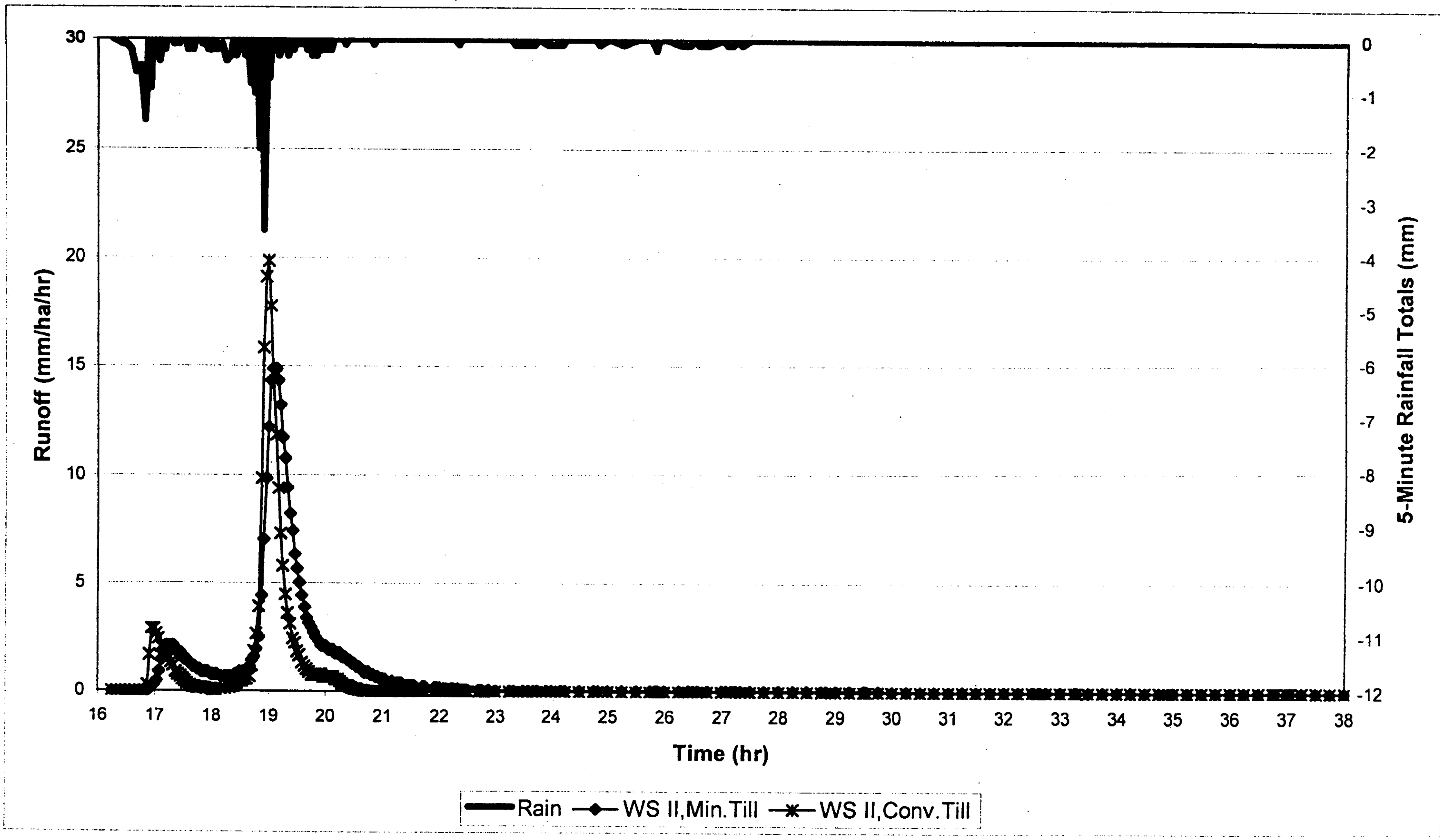

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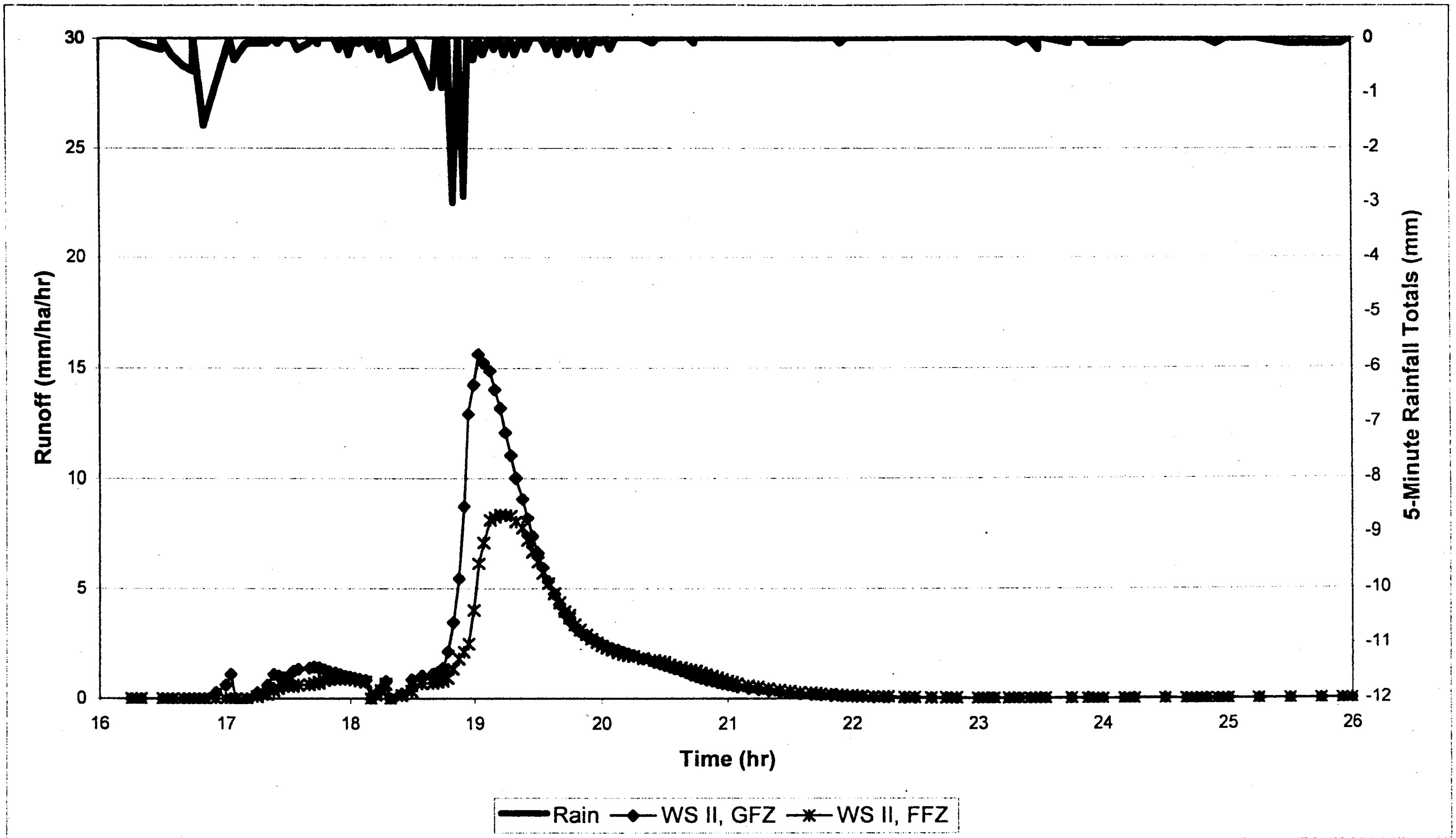

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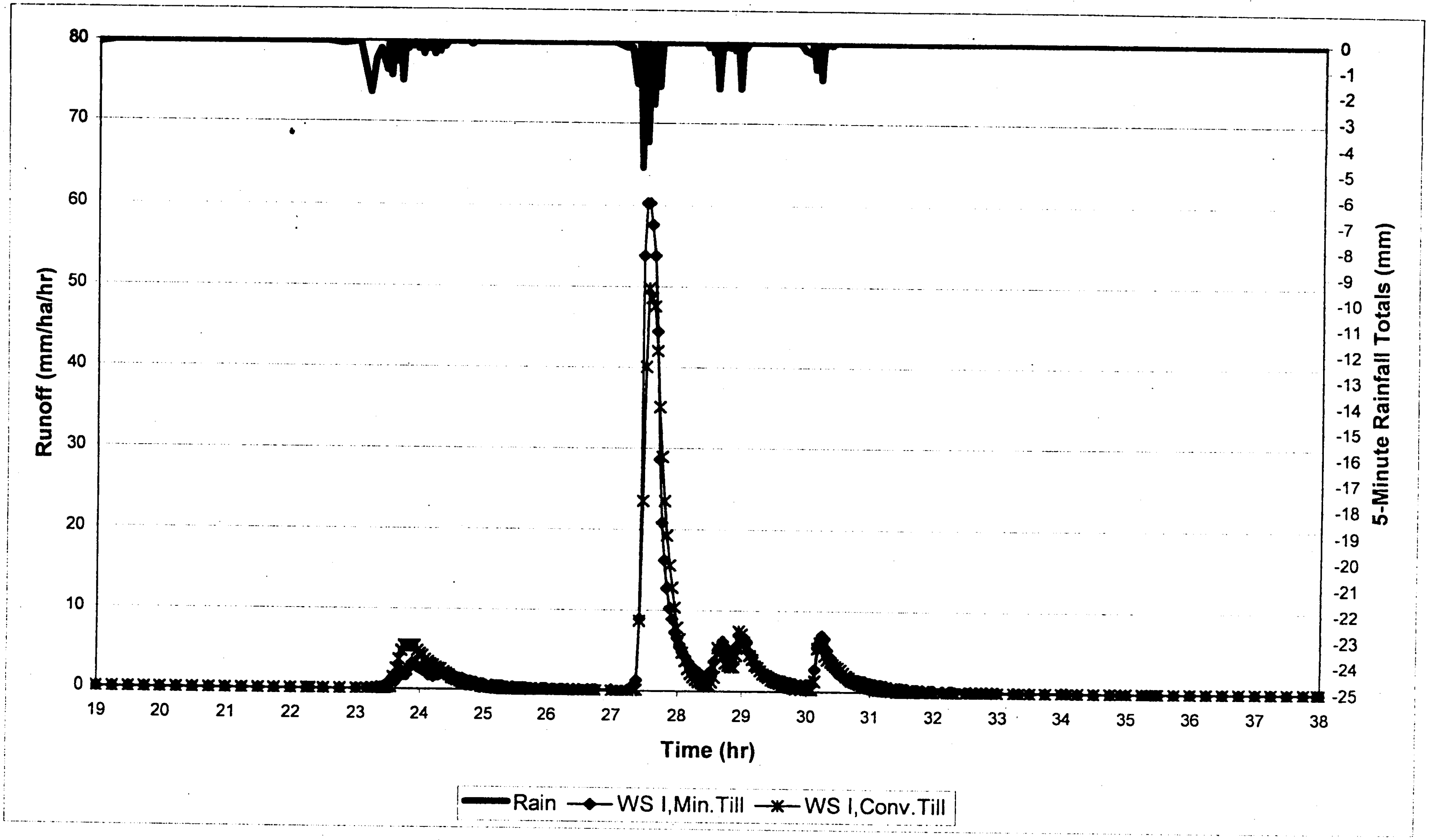

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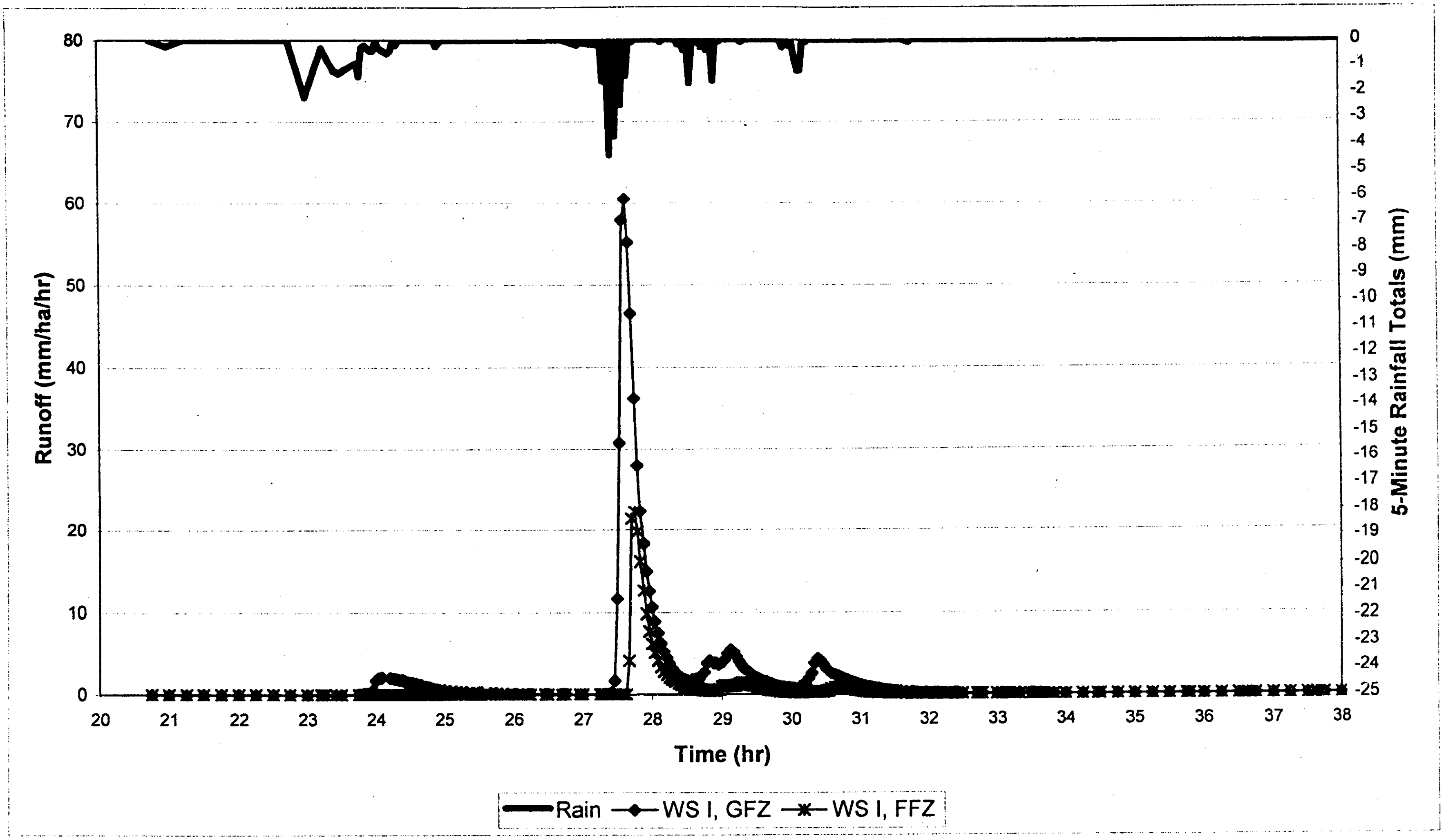

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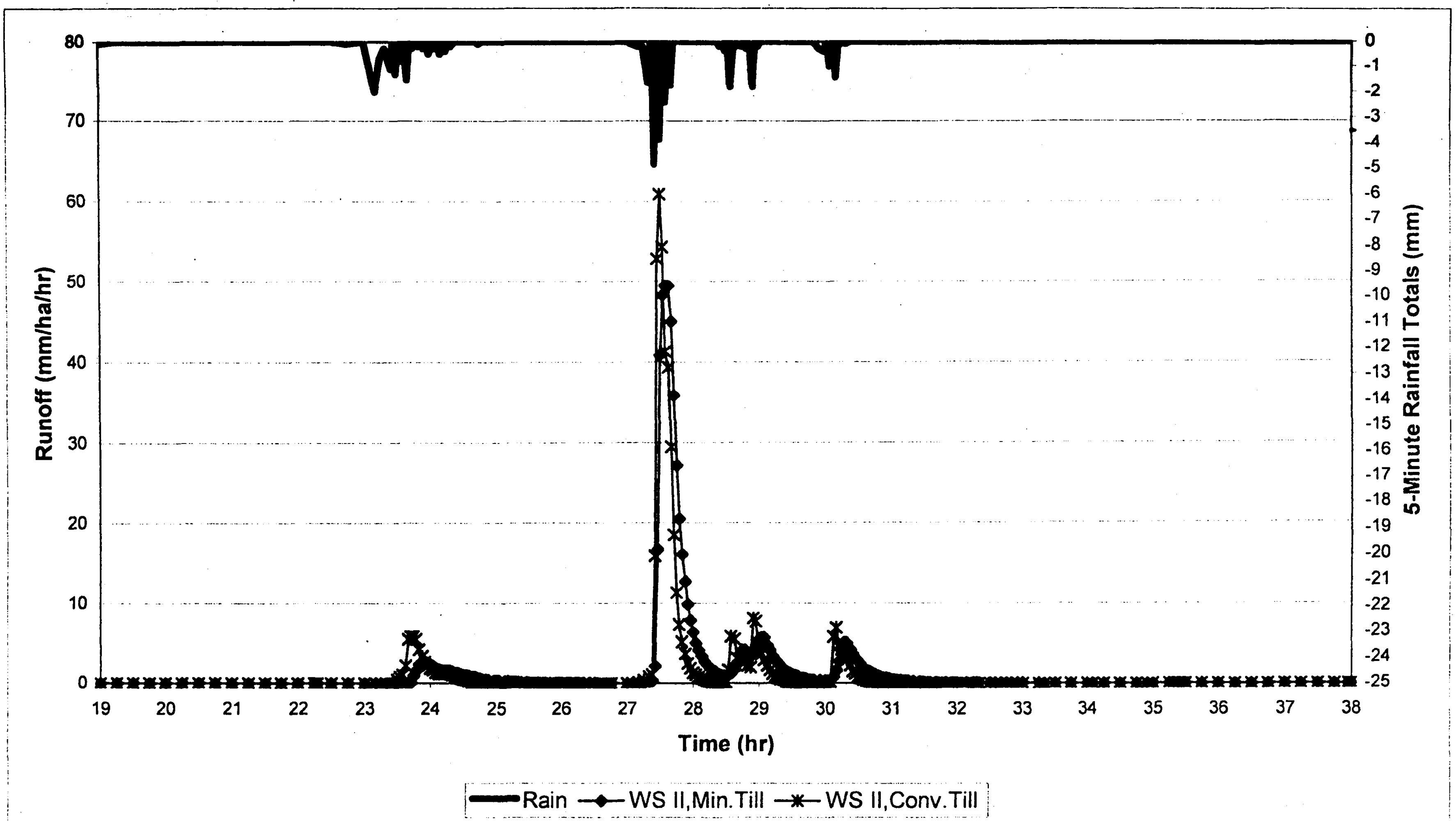

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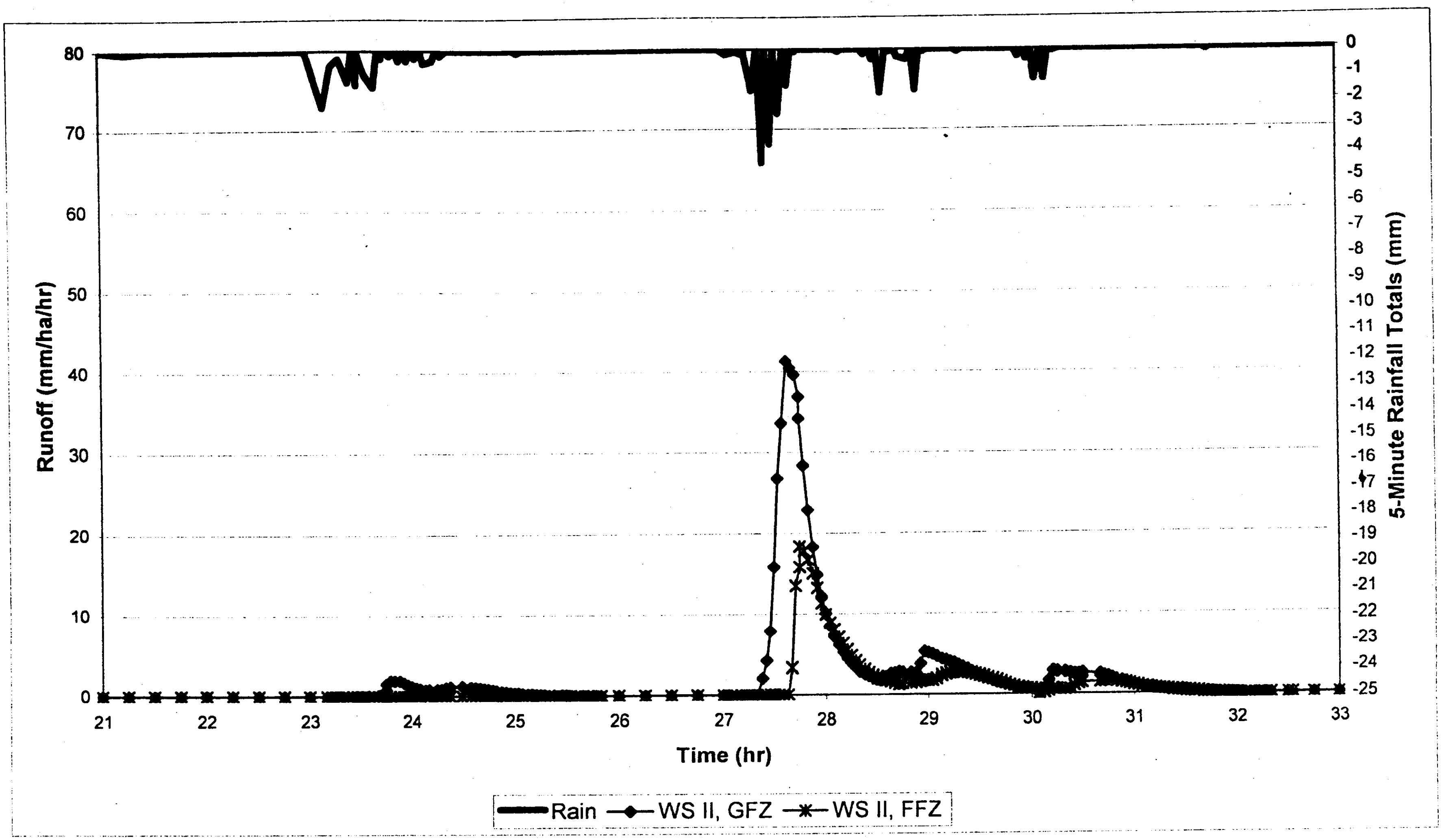

Storm Hydrograph for Oxford Grassed and Forested Filter Zones, Watershed II. Julian Day 351, 2000.