Hydrologic Modeling of an Agricultural Watershed in Quebec Using AGNPS

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Abstract

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A research study was undertaken to determine the predictive capability of the AGNPS model with respect to surface runoff, peak flow, and sediment yield produced by rainfall-runoff events on a 26 km^2 watershed in Quebec. Precipitation, stream discharge, surface runoff, and suspended sediment concentrations were monitored for rainfall-runoff events occurring from 1994-96, inclusive. Data describing stream patterns, topography, soil type, and land use were collected and input to the model.

Seven rainfall-runoff events were used for model calibration. Five storms were used to validate the model. Calibration curves were developed to correlate the antecedent precipitation index (API) to the SCS curve number. For model calibration, coefficients of performance of 0.05, 0.43, and 0.12 were obtained for surface runoff, sediment yield, and peak flow, respectively. For model validation, coefficients of performance (CP'_A) of 0.02, and 0.01 were obtained for surface runoff, and sediment yield, respectively. Peak flow was generally overpredicted and yielded a CP'_A of 2.07.

A sensitivity analysis showed API and associated curve numbers to be the most sensitive input parameters. USLE factors were also sensitive. The surface condition parameter and Manning's n had negligible influence on model output. The hydrograph shape factor toggle parameter showed extreme sensitivity.

A simulation of best management practices on the basin estimated soil loss reductions of 15 to 25% for storms of varying magnitudes if a 4-year crop rotation implementing conservation tillage were to be adopted.

Résumé

L'utilisation d'AGNPS pour la modélisation hydrologique d'un bassin versant agricole du Québec

La validité du modèle hydrologique AGNPS pour un bassin versant agricole de 26 km^2 a été évalué. Les écoulements de surface, les débits de pointe, et les charges de sol en suspension ont été simulés pour plusieurs événements hydrologiques. Pendant trois ans (1994-96), on a mesuré les débits de pointe, la pluie accumulée, les écoulements de surface, et les concentrations de sol en suspension produits par des événements hydrologiques. Des données topographiques, les charactéristiques des sols, et les différentes types de cultures ont été entrées dans le modèle.

Sept événements ont été utilisés pour la calibration du modèle. Cinq tempêtes ont été utilisées pour la validation du modèle. Des courbes de calibration ont été développés pour relier l'indice de pluie antécédente (IPA) au numéro de courbe SCS. Les événements de calibration ont produit des coefficients de performance (CP'_A) de 0.05, 0.43, et 0.12 pour les écoulements d'eau de surface, les charges de sediments, et les débits de pointe, respectivement. Les événements de validation ont produit des CP'_A respectifs de 0.02, et 0.01 pour les écoulements d'eau, et les charges de sol. En générale, les débits de pointes ont été sur-estimé, produisant un CP'_A de 2.07.

L'IPA et les numéros de courbes SCS étaient les paramètres les plus sensibles. Les facteurs USLE ont aussi démontré une sensibilté considérable. Le coefficient de condition de surface et le coefficient de Manning ont démontré une sensibilité négligeable. Une sensibilité extrême a été démontré par le facteur de forme d'hydrographe.

Une simulation des pratiques de gestion optimales sur le bassin utilisant une rotation culturale de 4 ans avec le déchaumage au chisel a estimé des réductions de la perte de sol de 15 à 25% pour des événements pluviométriques d'intensités variables.

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List of Symbols and Abbreviations Used

AGNPS	Agricultural Non-Point Source Pollution model
AMC	antecedent moisture content
ANSWERS	Areal Non-point Source Watershed Environment Simulation model
API	antecedent precipitation index
BMP	best management practice
C	USLE cover factor
CN	curve number
CP'_A	coefficient of performance
CREAMS	Chemicals, Runoff, and Erosion from Agricultural Systems model
EI	USLE energy-intensity value
EPIC	Erosion-Productivity Impact Calculator
ft.	feet
GIS	geographic information system
ha	hectares
km	kilometres
K	potassium USLE soil erodibility factor
l	litres
LS	USLE topographic factor
MAPAQ	Ministère de l'agriculture, des pecheries, et de l'alimentation du Québec
mm	millimetre
N	nitrogen
NO_3	nitrate
NH_4	ammonia
NPS	non-point source
P	phosphorus USLE practice factor
PO_4	phosphate
Q_p	peak flow rate
s	second
SCS	Soil Conservation Service
SWRRB	Simulator for Water Resources in Rural Basins
TKN	total Kjeldahl nitrogen
TP	total phosphorus
USLE	Universal Soil Loss Equation

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1.0 INTRODUCTION

1.1 Problem Definition

Non-point source pollution stemming from intensive agricultural production has been identified as a major contributor to water quality degradation in North America (Chesters et al., 1985). Sediment, nutrients, and pesticides discharged into watercourses through surface runoff and groundwater flows can degrade drinking water quality and cause health problems for humans (Thomann et al., 1987).

Diseases associated with drinking water of low quality continue to occur; e.g., acute gastrointestinal illness, hepatitis-A, giardiasis (Thomann et al., 1987). Pesticide concentrations exceeding acceptable levels for aquatic life have been measured on many agricultural watersheds in Quebec (Giroux et al., 1992). Interest in controlling water quality degradation at the watershed level is increasing (Laroche et al., 1995). Water quality models can be used to estimate the impact of agricultural practices on water quality, and assist in targeting areas with a high potential for water quality degradation, as well as aiding the selection of appropriate management practices.

Research has led to the development of many water quality models such as CREAMS: Chemicals, Runoff, and Erosion from Agricultural Management Systems (Knisel, 1980), ANSWERS: Areal Non-point Source Watershed Environment Response Simulation (Beasley et al., 1980), GLEAMS: Groundwater Loading Effects of Agricultural Management Systems (Leonard et al., 1986), AGNPS: Agricultural Non-Point Source Pollution Model (Young et al., 1985). More recently, such models have been integrated with Geographical Information Systems (GIS) to organize large amounts of input data to models (Mitchell et al., 1993; He et al., 1993; Srinivasan et al., 1994a).

The above models generally require input of watershed characteristics such as topography, channel width, length and slope, as well as information on soil type, (e.g., conductivity, porosity, antecedent moisture content) and land use (e.g., percent of crop cover, potential interception, etc...). Rainfall data can then be input to the models to simulate runoff, sediment, or nutrient transport.

Due to the tedium and excessive costs incurred by direct measurement, parameters are often obtained from the literature and adjusted by calibrating the model to obtain the best simulation for given conditions. However, calibration and validation of water and solute transport models can be time consuming when parameter values are chosen from the literature. Depending on the particular soil type in question, best simulations are sometimes obtained by using values considerably different from those generally quoted in the literature (Montas et al., 1991). It is possible that such values used in simulation may not accurately reflect actual watershed characteristics. This may lead to the use of erroneous input parameter values for future simulations. Direct measurement of watershed characteristics and, specifically, soil properties, should therefore be of interest to researchers and engineers involved in water quality management.

As the twenty-first century approaches, water quality issues will continue to be of utmost concern, as good quality water becomes scarcer, and human activities demand increasing fresh and clean water. Hydrologic models provide cost-effective means for determining best land management practices that minimize water quality degradation on agricultural watersheds. Such research needs to be performed in order to arrive at more effective soil and water conservation methods.

AGNPS is an event-based, distributed parameter computer simulation model developed by the Agricultural Research Service in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (Young et al., 1989). The model was initially developed to analyze the water quality of runoff from Minnesota watersheds. The model can be used to predict runoff volume, peak flow, as well as sediment, nutrient, and pesticide yields for single storm events at any point in a given watershed (Young et al., 1987). AGNPS has never been tested on Quebec watersheds.

1.2 Objectives

The specific objectives of this study were to:

1. Construct a database for the AGNPS model
2. Simulate surface runoff and sediment transport during rainfall events using AGNPS
3. Evaluate the predictive capabilities of AGNPS for rainfall/runoff events, as well as the relative effects of different best management practices
4. Perform a sensitivity analysis on the AGNPS model to determine which input parameters influence runoff and sediment transport most significantly.

1.3 Scope

A three-year study on the impacts of agricultural practices on the St. Esprit and Desrochers watersheds was recently initiated. The watersheds are located approximately 50 km northeast of Montreal between the towns of St. Esprit and St. Jacques. One of the project's objectives is to help farmers select best management practices to minimize the effects of agricultural production on water quality (Enright et al., 1995).

The St. Esprit watershed is one of the most intensely monitored watersheds ever studied in Quebec. A considerable amount of time and money have been spent in characterizing the hydrology, water quality, and land use of the above watersheds.

Due to the limits of time and funding, only one watershed (St. Esprit) was modeled. Therefore, results obtained are only applicable to the soils, climate, and general conditions of the study area. Hydrologic and water quality data were collected from January 1994 to December 1996. Due to the constraints of time and available data, rainfall/runoff events of 1994 were used to calibrate the AGNPS model. Events in 1995 and 1996 were used to validate the model.

2.0 LITERATURE REVIEW

Water resource degradation has become an issue of great social, political, and economic concern. Contribution of agricultural land use to non-point source pollution in the United States has been estimated at 64% of total suspended sediment and 76% of total phosphorus (Duda et al., 1985). The United States Environmental Protection Agency similarly noted that routine agricultural activities were responsible for more than 60% of surface water contamination (USEPA, 1990). Nevertheless, the management of non-point source pollution continues to be politically, economically, and socially difficult as well as technically complex (Young et al., 1989).

Regulatory agencies in Canada and the United States have envisioned reducing agricultural non-point source (NPS) pollution through the following means: 1) identification of areas most susceptible to NPS pollution; 2) implementation of Best Management Practices (BMP's) on these areas; 3) assessment of BMP implementation effectiveness on water quality improvement through monitoring strategies (Castle, 1993). Targeting specific areas within a watershed possessing greater potential for soil and nutrient losses will allow for more efficient use of public funds with respect to the alleviation of water pollution problems (Young et al., 1989).

However, hydrologic data tend to be more readily available for large rivers; small rural watersheds are not often gauged (Enright, 1988). As a result, hydrologic water quality computer modeling has gained wide acceptance as a cost-effective tool for developing and predicting the effects of best management practices on water quality (Tim et al., 1994).

2.1 Hydrologic Water Quality Modeling

2.1.1 General modeling overview

The development of various hydrologic models has aided in developing targeting measures aimed at improving water quality at the watershed level. Some of these models include CREAMS (Chemicals, Runoff, and Erosion from Agricultural

Management Systems) (Knisel, 1980); EPIC (Erosion-Productivity Impact Calculator) (Williams et al., 1982); ANSWERS (Areal Non-point Source Watershed Environment Response Simulation) (Beasley et al., 1980); SWRRB (Simulator for Water Resources in Rural Basins) (Williams et al., 1985); AGNPS (AGricultural Non-point Source Pollution) (Young et al., 1985). All these models have been tested on watersheds in the United States (Bingner et al., 1989).

CREAMS is a continuous, field-scale model developed to predict non-point source pollution. It requires the input of parameters depicting several overland and channel slope segments; the model can use breakpoint rainfall and allows for the update of certain input parameters during the simulation (Bingner et al., 1989). Runoff and sediment yield are predicted using modified versions of the SCS runoff curve number method, and the USLE, respectively.

EPIC and SWRRB are continuous, total storm rainfall event models that assume watershed soils and topography to be homogeneous, and do not allow for the update of parameters (Bingner et al., 1989). They are both sediment yield models that describe a watershed with one slope length and one channel length. SWRRB was formulated to evaluate the effect of management decisions on runoff and sediment yield for small, ungauged agricultural watersheds throughout the U.S.; EPIC was developed to determine the relationship between erosion and soil productivity in the U.S. (Bingner, 1989). Both models use the CREAMS method and a modified USLE to predict surface runoff, and sediment yield, respectively.

ANSWERS and AGNPS were originally developed as single-event models that did not provide for the update of watershed parameters during simulation. ANSWERS was developed to simulate sediment transport on rural watersheds during and immediately after a rainfall event; AGNPS was formulated to simulate sediment, nutrient, and pesticide movement resulting from a single event (Bingner, 1989). Both models can simulate the hydrology of small and very large watersheds (several thousand hectares). AGNPS uses the unmodified version of the SCS curve number method to predict surface runoff, and a self-modified version of the USLE to predict sediment yield. ANSWERS applies an explicit, backward difference solution of the continuity equation combined with Manning's equation to determine runoff; an equation describing the detachment of soil particles by raindrops (Meyer et al., 1969) combined with an equation for the detachment of particles by overland flow (Meyer et al., 1969) as modified by Foster (1976) produces sediment yield (Bingner, 1989).

All five models have produced results with varying degrees of success. Bingner et al. (1989) evaluated the performance of all five models and concluded that no one model worked well in every runoff and sediment yield scenario. However, CREAMS and SWRRB best simulated measured values followed by AGNPS, EPIC, and ANSWERS, though the authors did note that the latter model's accuracy could have been improved through the use of updatable parameters. The models were formulated with different aims in mind and in different regions of the United States. It is therefore not surprising to observe a wide range of behavior for each model.

2.1.2 CREAMS and ANSWERS model applications

CREAMS and ANSWERS are two of the most commonly used hydrologic water quality models (Bingner et al., 1989). These models have been used for a variety of purposes and have been applied to differing hydrologic conditions.

For example, Bengston et al. (1985) used CREAMS to estimate annual surface runoff on a 1.6 ha field in the lower Mississippi Valley to within 2.1 percent. It was also reported that nitrogen losses were overestimated, and phosphorus losses underestimated. Rudra et al. (1985), applied CREAMS to small plots in Southern Ontario. Erosion submodel performance was found to be erratic but within acceptable limits; soluble phosphorus was better predicted than sediment P though slight modification of the model was necessitated (Yoon et al., 1992). In the St. Laurence Lowlands of Quebec, Enright et al. (1990) found that the CREAMS hydrology submodel (based on SCS curve numbers) drastically underpredicted surface runoff during the summer. In a later study on the same site, CREAMS was observed to underestimate event percolation depths and overpredict nitrate concentrations in the drainflow (Madramootoo et al., 1995). Yoon et al. (1992) applied CREAMS to a field-sized watershed under cotton in the Limestone Valley of northern Alabama. By using field-based curve numbers, runoff simulation on conventional and conservation till plots was improved to 56-63%, and 67-98% of observed runoff, respectively,. Sediment loss was adequately predicted under conservation tillage, but was underpredicted on conventional till plots. Nitrogen and phosphorus losses were generally underestimated except for accurate P loss simulation on conventional till. Zhang et al. (1995) used CREAMS to predict phosphorus loading from South Florida's Lake Okeechobee Watersheds. It was concluded that the model provided a reasonable estimate of monthly runoff and phosphorus loading.

The ANSWERS model has been validated and used in various locations in North America (Beasley et al., 1980b; Breve et al., 1989; Park et al., 1982). ANSWERS is currently being integrated within a GIS (SPANS) to simulate runoff and erosion from a watershed in Southern Quebec (Mousavizadeh et al., 1995). Razavian (1990) used ANSWERS to study the hydrologic responses of a rural watershed in southeast Nebraska. Various physiographic, hydrologic, meteorologic, and management conditions were simulated. Montas et al. (1991) used ANSWERS to predict runoff and soil loss from two small agricultural watersheds in Southwestern Quebec. Peak flow was generally underpredicted, and time to peak, overpredicted. A seasonal adjustment of infiltration parameters improved runoff predictions, but still underestimated soil loss. Following this research, Montas et al. (1992) developed a Decision Support System (DSS) for the planning of soil conservation systems on a watershed scale. The system integrated Geographical Information Systems, distributed modeling, and Expert System technologies. The DSS was used to target areas most susceptible to erosion and to select appropriate soil conservation practices. Sediment yield and average erosion rate reductions of 50% were attained.

2.1.3 AGNPS model applications

AGNPS has been similarly applied to various hydrologic water quality modeling studies. It has been used in the United States to identify the potential for and severity of water quality problems associated with intensive agricultural practices.

The model is best applied in the evaluation of management practices with respect to a watershed's water quality.

Validation of the AGNPS model for sediment and water yield was demonstrated by Koelliker et al. (1989) on five watersheds in Kansas. Summer et al. (1990) linked AGNPS to a one-dimensional water body model (LAKE) in order to simulate watershed-lake system responses to land management and weather conditions. Terrain analysis methods were integrated with AGNPS to permit better representation of terrain effects on runoff and erosion processes (Panuska et al., 1991). AGNPS was applied to target cost-effective cropland retirement programs that would reduce agricultural non-point source pollution while maintaining adequate levels of land productivity (Kozloff et al., 1992). Sugiharto et al. (1994) used AGNPS to evaluate 20 management practices with respect to sediment and phosphorus yields from 4 ha fields in a 1272 ha watershed composed of dairy farms.

In recent years, great interest has been shown with respect to linking hydrologic models with Geographical Information Systems; AGNPS is no exception. Ventura et al. (1988) developed a GIS to locate areas of excessive erosion; Hession et al. (1989) extracted data from a GIS to run AGNPS and evaluate best management practices for several Virginia watersheds (Srinivasan et al., 1994). Erosion hot spots and best management practices were similarly determined for watersheds in Southern Iowa and Saginaw Bay, Michigan (Tim et al., 1994; He et al., 1993, respectively). Erosion problems at the Bajun River Basin and the Tsengwen Reservoir Watershed in Taiwan were quantified using an integrated GIS-AGNPS system (Lo, 1995). These regions represent annual soil losses estimated to reach 259, and 903 t/ha, respectively.

Sensitivity analyses of AGNPS input parameters have formed the subject of several studies. Young et al. (1987) reported that the cell land slope, soil erodibility, cropping factor, and curve number are the variables most significantly affecting sediment yield and sediment-associated nutrient yields. Feezor et al. (1989) evaluated the effect of cell size on AGNPS prediction for a watershed in west-central Illinois. Srinivasan et al. (1991) evaluated the effects of the four slope prediction methods of the USLE "LS" factor. Results showed the maximum slope method to overpredict erosion by 1.6 to 2.0 times when compared to the USLE equation for flat and steep areas, respectively. In a later study, it was determined that slope steepness and slope length play a major role in estimating sediment and phosphorus movement within a watershed (Srinivasan et al., 1994). However, Mitchell et al. (1993) reported no significant differences between the four slope estimation methods; it was also stated that antecedent moisture condition was the most sensitive parameters for the watersheds studied.

2.2 AGNPS Model Description and Structure

AGNPS is an event-based non-point source pollution model specifically developed to evaluate agricultural watersheds. The model simulates surface runoff, sediment, nutrient (nitrogen and phosphorus), and pesticide transport. AGNPS also provides for input of sediment and nutrient point-sources such as animal feedlots (Young et al., 1989).

The model operates on a grid system whereby the watershed area is divided into cells of a predetermined size. The cells are oriented from the watershed's upper left-hand corner and are numbered from left to right. A maximum of 28 000 cells can be used with most watershed characteristics expressed at the cell level (Young et al., 1994).

Calculations made by AGNPS are performed in loops or stages. Initial calculations such as estimates for upland erosion, surface runoff depth, time of concentration, runoff sediment and soluble pollutant levels for all cells are made in the first loop (Young et al., 1987). Calculations of overland flows and sediment yields leaving primary cells are then performed during the second stage; primary cells are defined as those which no other cell drains into (Young et al., 1987). Sediment is divided into five classes: sand, silt, clay, small aggregates, and large aggregates. Finally, surface runoff, sediment, and nutrients are routed through the watershed in loop 3.

2.2.1 Hydrology

Depth of runoff estimates are based on the SCS curve number method which uses the following equation (USDA SCS, 1972):

$$Q = (P - 0.2S)^2/(P + 0.8S) \qquad \{2.1\}$$

where Q = runoff depth (mm, inches)
P = rainfall (mm, inches)
S = a retention parameter (mm, inches)

The retention parameter is defined as:

$$S = 25\,400/CN - 254 \qquad \text{(Metric units)} \qquad \{2.2\}$$
$$S = 1000/CN - 10 \qquad \text{(Imperial units)}$$

This method was chosen because of its simplicity and widespread use (Young, 1989).

Peak flow is calculated using the empirical relationship developed for the CREAMS model by Smith and Williams, 1980:

$$Q_p = 3.79A^{0.7}CS^{0.16}(RO/25.4)^{0.903A^{0.017}}LW^{-0.19} \qquad \{2.3\}$$

where Q_p = peak runoff rate (m^3/s)
A = watershed area (km^2)
CS = channel slope (m/km)
RO = runoff volume (mm)
LW = watershed length-width ratio, equal to the square of the length over the width (m^2/m)

2.2.2 Erosion and sediment transport

Upland erosion is estimated using a modified version of the universal soil loss equation (Wischmeier and Smith, 1978):

$$SL = (EI)\ KLSCP\ (SSF) \qquad \{2.4\}$$

where SL = soil loss
EI = product of storm kinetic energy and maximum 30-minute intensity
K = soil erodibility factor
LS = topographic factor
C = cover and management factor
P = supporting practice factor
SSF = slope shape factor

Sediment loss is determined for each cell and is then routed through the watershed using sediment transport relationships proposed by Foster et al. (1981) and Lane et al. (1982). The basic routing equation is derived from the steady state continuity equation:

$$Q_s(x) \quad = \quad Q_s(0) + Q_{sl}(x/L_r) - \int_0^x (x)\, w\, dx \qquad \{2.5\}$$

where $Q_s(x)$ = sediment discharge at downstream end of channel reach
$Q_s(0)$ = sediment discharge into upstream end of channel reach
Q_{sl} = lateral sediment inflow rate
x = downstream distance
L_r = reach length
w = channel width

The deposition rate is estimated as follows:

$$D(x) \quad = \quad [V_{ss} / q(x)]\,[q_s(x) - g_s'(x)] \qquad \{2.6\}$$

where $D(x)$ = deposition rate
V_{ss} = particle velocity
$q(x)$ = discharge per unit width
$q_s(x)$ = sediment load per unit width
$g_s'(x)$ = effective transport capacity per unit width

A modification of the Bagnold stream power equation is used to calculate the effective transport capacity (Bagnold, 1966):

$$g_s'(x) \quad = \quad \eta\, g_s \quad = \quad \eta\, k\, [\tau\, v^2 / V_{ss}] \qquad \{2.7\}$$

where g_s = the transport capacity
η = an effective transport vector
k = the transport capacity factor
τ = the shear stress
v = average channel flow velocity (Manning's equation)

Values for the effective transport capacity are given by Young et al. (1986).

Sediment load for each of the five particle classes leaving a cell is calculated using the following equation:

$$Q_s(x) \quad = \quad [2q(x)/(2q(x) + \Delta x V_{ss})]\{Q_s(0)+Q_{sl}(x/l) - w\Delta x/2[V_{ss}/q(0)[q_s(0) - g_s'(0)]-V_{ss}/q(x)\ \ g_s'(x)]\} \qquad \{2.8\}$$

Equation is the basic routing mechanism that drives the transport model. Chemical transport equations can be found in Young et al. (1989).

2.3 Problems Associated With the SCS Curve Number Method

2.3.1 The SCS Curve Number Method

The curve number (CN) method was developed by the United States Soil Conservation Service to provide a basis for estimating the effects of crop cover and land management on runoff produced by storm rainfall (Enright, 1988; SCS, 1972). Equations {2.1} and {2.2} describe the SCS procedure. A smaller curve number represents a lower volume of runoff, and a larger CN, a relatively higher runoff volume. Differences in antecedent moisture content were also provided for: adjustments to the curve number based on rainfall occurring 5 days prior to the event in question were described (Table 2.1). These adjustments were represented by three antecedent moisture conditions (AMC's). AMC III represents wet conditions, AMC

Table 2.1 SCS Curve Number Antecedent Moisture Conditions (AMC)

		5-Day Antecedent Rainfall (mm)	
AMC	**General Description**	**Dormant Season**	**Growing Season**
I	Optimum soil condition from about lower plastic limit to wilting point	< 13	< 36
II	Average value for annual floods	13-28	36-53
III	Heavy rainfall or light rainfall and low temperatures within 5 days prior to the given storm	> 28	> 53

(Source: Schwab et al., 1981)

provides for dry conditions, while AMC II represents the average moisture condition for annual floods. AMC I decreases curve numbers proportionally, while AMC increases them. Curve numbers for various hydrologic soil cover conditions are shown in Table 2.2.

Table 2.2 Curve Numbers for Hydrologic Soil Cover Conditions (AMC II)

Land Use or cover	Treatment or practice	Hydrologic Condition	A	B	C	D
Fallow	Straight Row	-------------	77	86	91	94
Row Crops	Straight Row	poor	72	81	88	91
		good	67	78	85	89
	Contoured	poor	70	79	84	88
		good	65	75	82	86
	Terraced	poor	66	74	80	82
		good	62	71	78	81
Small Grain	Straight Row	poor	65	76	84	88
		good	63	75	83	87
	Contoured	poor	63	74	82	85
		good	61	73	81	84
	Terraced	poor	61	72	79	82
		good	59	70	78	81
Close-seeded legumes or rotation meadow	Straight Row	poor	66	77	85	89
		good	58	72	81	85
	Contoured	poor	64	75	83	85
		good	55	69	78	83
	Terraced	poor	63	73	80	83
		good	51	67	76	80
Pasture or range		poor	68	79	86	89
		fair	49	69	79	84
		good	39	61	74	80
	Contoured	poor	47	67	81	88
		fair	25	59	75	83
		good	6	35	70	79
Meadow (permanent)		good	30	58	71	78
Woods		poor	35	66	77	83
		fair	36	60	73	79
		good	25	55	70	77

(Source: Schwab et al., 1981)

2.3.2 Modifications and alternatives to the SCS Curve Number Method

SCS Curve numbers were developed empirically with data collected from research watersheds in the United States. Chen (1981) stated that there is no way of knowing how the relationships between the three antecedent moisture conditions were developed. Choice of the 5-day AMC criterion is also unclear (Enright, 1988).

One of the major weaknesses of the SCS curve number method is the discrepancy between published values and those determined adequate for use in the field (Smith et al., 1978). Incorrect curve numbers can lead to gross errors in runoff estimation (Yoo et al., 1993). Hawkins (1979) stated that antecedent moisture condition variations are not well represented by the SCS method. Hjelmfelt et al. (1982) suggested that the interaction of variables such as individual storm characteristics, tillage, plant growth, and temperature with antecedent moisture were considerable enough to prohibit the use of AMC alone in explaining curve number variation (Yoo et al., 1993). Using 585 storm events from 36 watersheds, Bales et al. (1982) found that when using AMC II exclusively, the CN method underpredicted observed runoff volumes 93 % of the time. Madramootoo et al. (1988) demonstrated that the SCS curve number method is inappropriate for estimating surface runoff in the Ottawa-St. Lawrence region.

Several variations to the SCS curve number method have been proposed over the years. Hanson et al. (1981) developed curve numbers for northern plains rangeland. Steichen (1983) showed seasonal variations of CN under different tillage practices. Modifications to the SCS method were necessitated in order to simulate runoff in the coastal plains of the eastern United States (Sheridan et al., 1986). Hauser et al. (1991) incorporated the log-normal probability distribution of the retention parameter, S, in equation {2.1} to determine curve numbers for the three AMC's.

An alternate method of determining antecedent moisture is described by the antecedent precipitation index, P_a (Bruce et al., 1966). This index is calculated from rain or snowfall data for a number of days before a given event. The antecedent precipitation index for day 0 is given by

$$P_{a0} = kP_1 + k^2P_2 + \ldots + k^nP_n \qquad \{2.9\}$$

where $P_1, P_2, \ldots P_n$ = precipitation depth 1, 2, ... n days prior to the event
k = a constant < 1

Foroud (1978) demonstrated that the antecedent precipitation index (API) was an appropriate indicator of antecedent moisture conditions for Quebec watersheds when applied to infiltration equations. Monfet (1979) suggested using the API and the time of year to modify the SCS curve number method for Quebec conditions. The antecedent precipitation index was also used by Hoang (1979) to distinguish three antecedent precipitation conditions:

Condition 1	-	$0 \leq API \leq 15$ mm
Condition 2	-	$15 \leq API \leq 30$ mm
Condition 3	-	$API > 30$ mm

Using these criteria, empirical equations describing runoff as a function of total rainfall were developed for watersheds in the Estrie region located on the south shore of the St. Lawrence river. Three formulas were developed, one for each API condition. For equation {2.9}, values of 0.85, and 14, for k, and n, respectively, were deemed adequate for Quebec watersheds (Monfet, 1979).

2.4 Watershed Modeling in Quebec

Several studies concerned with the hydrologic modeling of Quebec watersheds have been initiated in recent years. Several conclusions have been made regarding the nature of watershed modeling in certain areas of this province. However, few generalities can be inferred with respect to the entire region.

Enright (1988) used the SCS method and the Green Ampt Mein Larson (GAML) model (Mein et al., 1973) to simulate runoff on a small rural watershed in southwestern Quebec. The study arrived at several conclusions. As stated earlier, it was determined that the antecedent moisture criteria established by the SCS are not applicable to the Ottawa-St. Lawrence lowlands. Depth of surface runoff was consistently underpredicted when the AMC criteria were applied. It was also observed that the SCS curve number method produced best results when a seasonal adjustment of curve numbers was used. The GAML model produced best simulations when measured soil properties were input to the model. Overall, the GAML model produced better results then the SCS method.

Madramootoo et al. (1989) came to some further conclusions regarding the use of the GAML model in southwestern Quebec. The model's inherent assumption of a homogeneous soil with uniform initial soil moisture was sited as a major problem. The use of soil nomographs developed by Rawls et al. (1983) was considered inappropriate for Quebec soils. The development of a more accurate method of measuring initial soil moisture and suction at the soil wetting front was recommended.

Barry et al. (1990) used the HYFOR model (Fox, 1976) to simulate snowmelt runoff on the Lac Laflamme watershed, a small 68 ha basin located north of Quebec City. Reasonable simulations of surface runoff, subsurface flow, soil water and groundwater level were achieved by altering selected porosity and hydraulic conductivity parameters. Simulations indicated that surface flow may contribute more than 60% of daily runoff during snowmelt.

A detailed study of peak flow prediction on small Quebec watersheds was conducted by Montas et al. (1990). The following observations were reported: the Kirpich and SCS Uplands equations underestimated time of concentration; the SCS Lag, Mockus, Airport, and SWRRB methods reasonably estimated time of concentration; the ANSWERS model best estimated peak flow, though its lengthy input data requirement was sited as a drawback; the SCS Triangular Hydrograph Method as modified by Monfet (1979) produced reasonable results.

The use of ANSWERS as a modeling tool for runoff and soil loss prediction in southwestern Quebec was elaborated upon by Montas et al. (1991). Twenty-four rainfall events were modeled for runoff, and seven for sediment yield. Good runoff prediction was achieved through a seasonal adjustment of infiltration parameters. However, sediment yield was underpredicted for all seven events considered.

Schell et al. (1992) used radar measured rainfall and the HYMO model to predict runoff on a watershed in southwestern Quebec. High intensity, short duration rainstorms were well-modeled by HYMO with both radar and recording raingauge data. However, best hydrograph simulations were obtained using radar data. Neither method of rainfall determination resulted in the successful modeling of long duration, low intensity storms.

Hydrologic modeling of watersheds in Quebec is well-documented. Several methods have arrived at reasonable estimates of runoff and peak flow predictions for rainfall-runoff events. Nevertheless, it is extremely difficult to determine beforehand what method of simulation is best suited to any particular region of the province. More research needs to be performed at the watershed level in order to understand hydrologic processes, select appropriate hydrologic models, and select BMP's. The AGNPS model can simulate an agricultural basin's water quality and aid in the performance of the above functions. Furthermore, the applicability of AGNPS to Quebec conditions has not been studied. Such research will contribute to reducing non-point source pollution from agricultural watersheds.

3.0 METHODOLOGY

The St. Esprit watershed is located approximately 50 km northeast of Montreal between the towns of St. Esprit and St. Jacques. The basin covers an area of approximately 26.1 km^2. A map showing the location of the watershed with respect to the island of Montreal is given in Figure 3.1.

3.1 Site Description

Of the St. Esprit watershed's 26.1 km^2 area, roughly 1659 ha (63.6%) representing 25 farms are in crop production; approximately 61% of the cropped area is under grains or soya, with a majority of this percentage (37.8%) representing corn. The remaining area is covered by 575 ha (22%) of forested and 376 ha (14.4%) of non-cropped land. Yearly land use distribution on the cropped portion of the watershed is shown in Table 3.1. Land-use was determined through aerial photograph interpretation. Variation of land-use on the watershed area is shown in Figure 3.2.

Table 3.1 Agricultural Land Use on the St. Esprit Watershed

Land-use	Average for 1994-96	
	Area (ha)	Area (%)
Grains and Soya	1013	61.1
Vegetables	246	14.8
Hay	400	24.1
Total	1659	100.0

Soil textures in the watershed are variable with the majority of crop production occurring on heavier soils (Lapp, 1996). The distribution of soil textural classes in the basin is shown in Table 3.2 (Enright et al., 1995). A soil texture map is shown in Figure 3.3

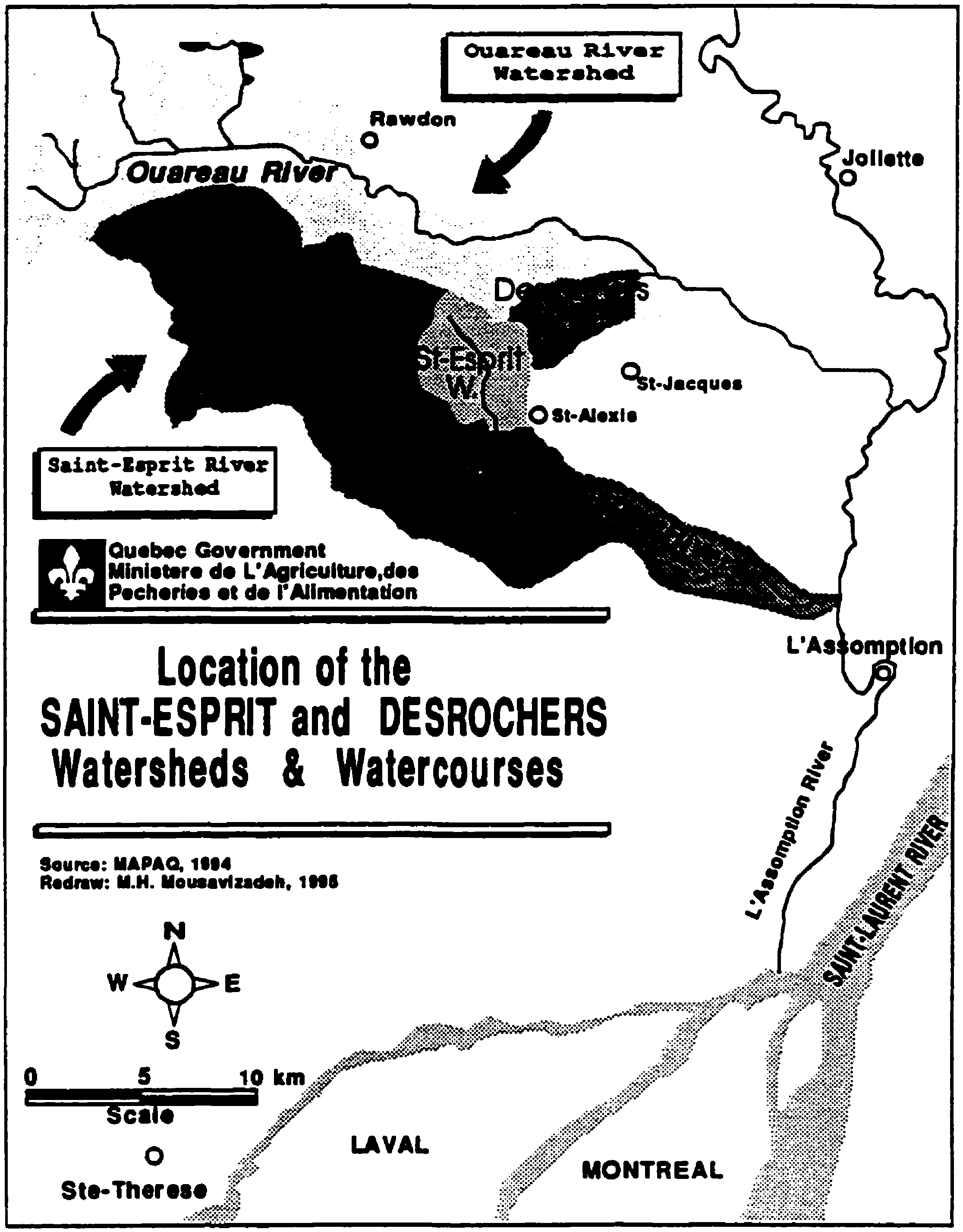

Ouareau River Watershed
Rawdon
Joliette
Ouareau River
St-Esprit W.
St-Jacques
St-Alexis
Saint-Esprit River Watershed
Quebec Government
Ministere de L'Agriculture,des
Pecheries et de l'Alimentation
Location of the
SAINT-ESPRIT and DESROCHERS
Watersheds & Watercourses
Source: MAPAQ, 1994
Redraw: M.H. Mousavizadeh, 1995
L'Assomption
L'Assomption River
SAINT-LAURENT RIVER
N
W
E
S
0 5 10 km
Scale
Ste-Therese
LAVAL
MONTREAL

Fig. 3.1

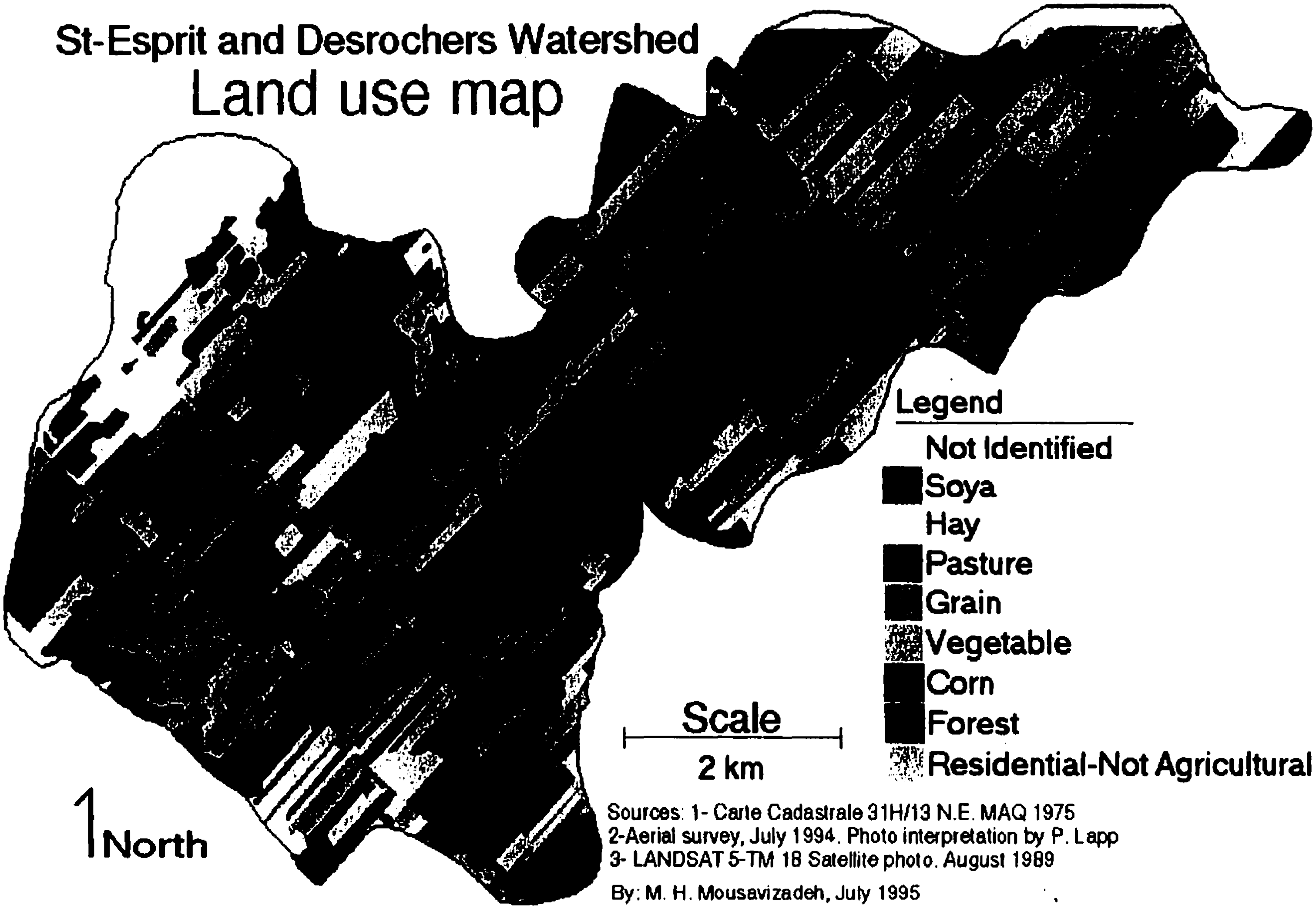

St-Esprit and Desrochers Watershed
Land use map
Legend
Not Identified
Soya
Hay
Pasture
Grain
Vegetable
Corn
Forest
Residential-Not Agricultural
Scale
2 km
North
Sources: 1- Carte Cadastrale 31H/13 N.E. MAQ 1975
2-Aerial survey, July 1994. Photo interpretation by P. Lapp
3- LANDSAT 5-TM 18 Satellite photo. August 1989
By: M. H. Mousavizadeh, July 1995

Fig. 3.2

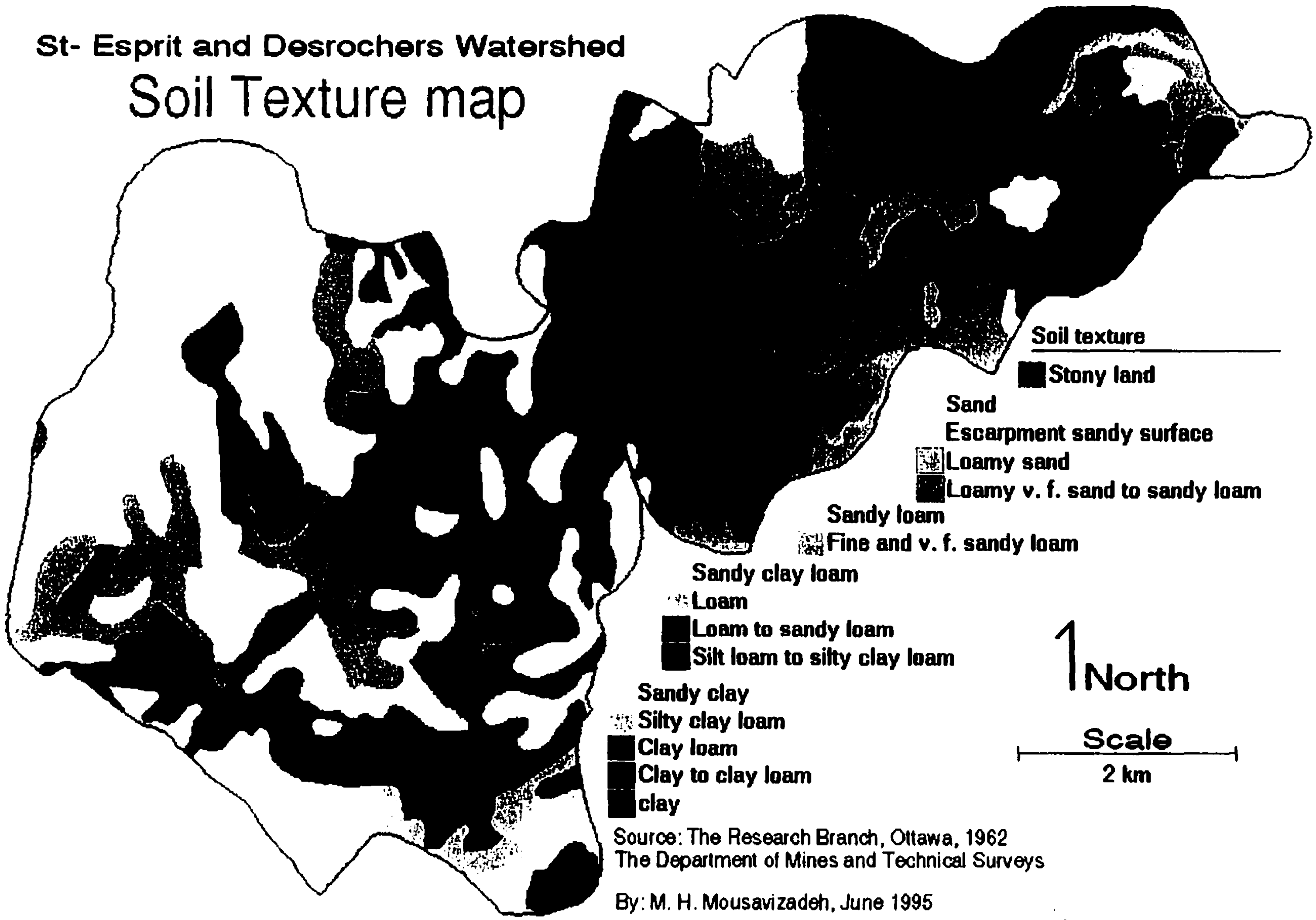

St- Esprit and Desrochers Watershed
Soil Texture map
Soil texture
Stony land
Sand
Escarpment sandy surface
Loamy sand
Loamy v. f. sand to sandy loam
Sandy loam
Fine and v. f. sandy loam
Sandy clay loam
Loam
Loam to sandy loam
Silt loam to silty clay loam
Sandy clay
Silty clay loam
Clay loam
Clay to clay loam
clay
North
Scale
2 km
Source: The Research Branch, Ottawa, 1962
The Department of Mines and Technical Surveys
By: M. H. Mousavizadeh, June 1995

Fig. 3.3

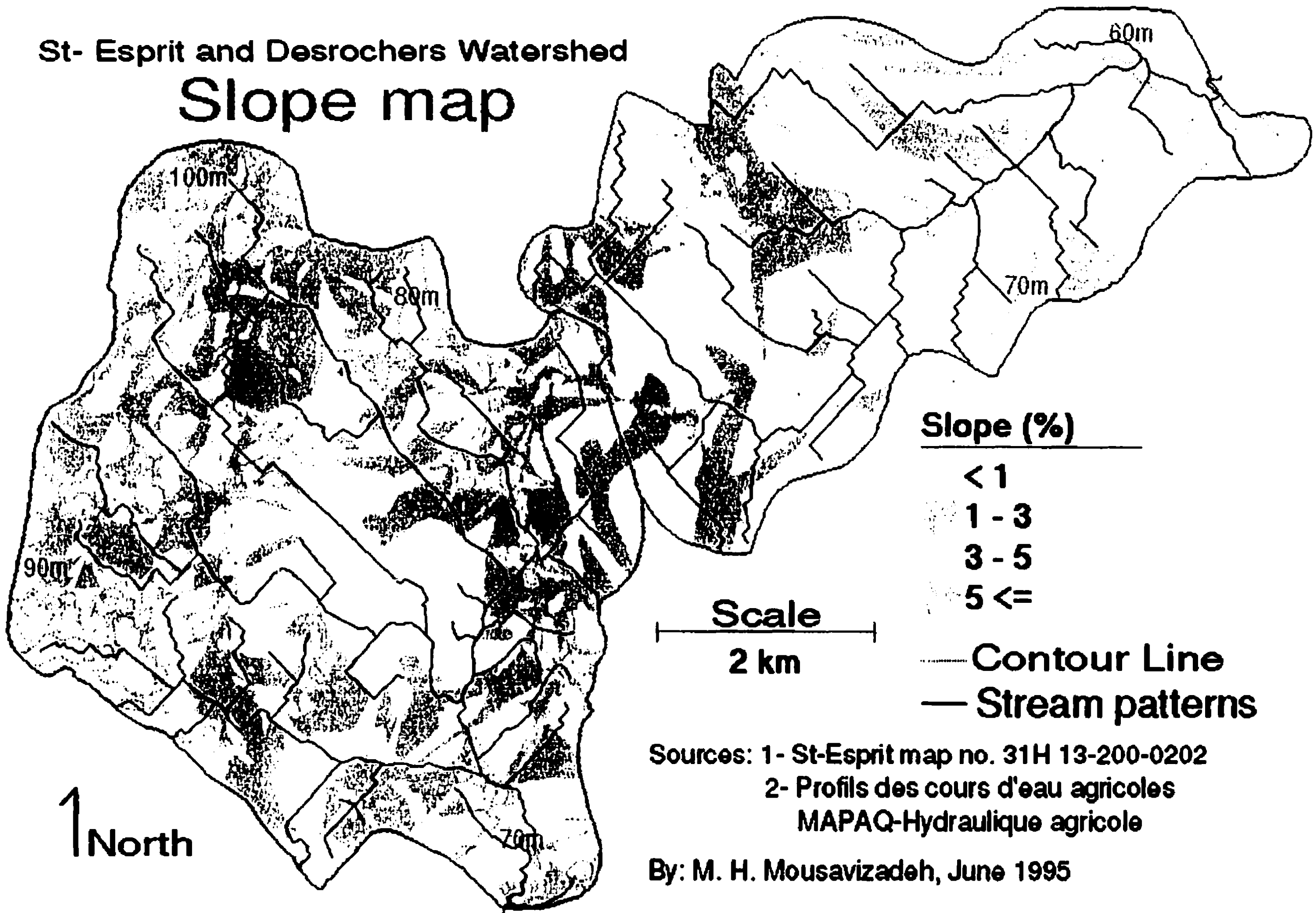

St- Esprit and Desrochers Watershed
Slope map
100m
80m
90m
70m
60m
70m
North
Slope (%)
< 1
1 - 3
3 - 5
5 <=
Scale
2 km
Contour Line
Stream patterns
Sources: 1- St-Esprit map no. 31H 13-200-0202
2- Profils des cours d'eau agricoles
MAPAQ-Hydraulique agricole
By: M. H. Mousavizadeh, June 1995

Fig. 3.4

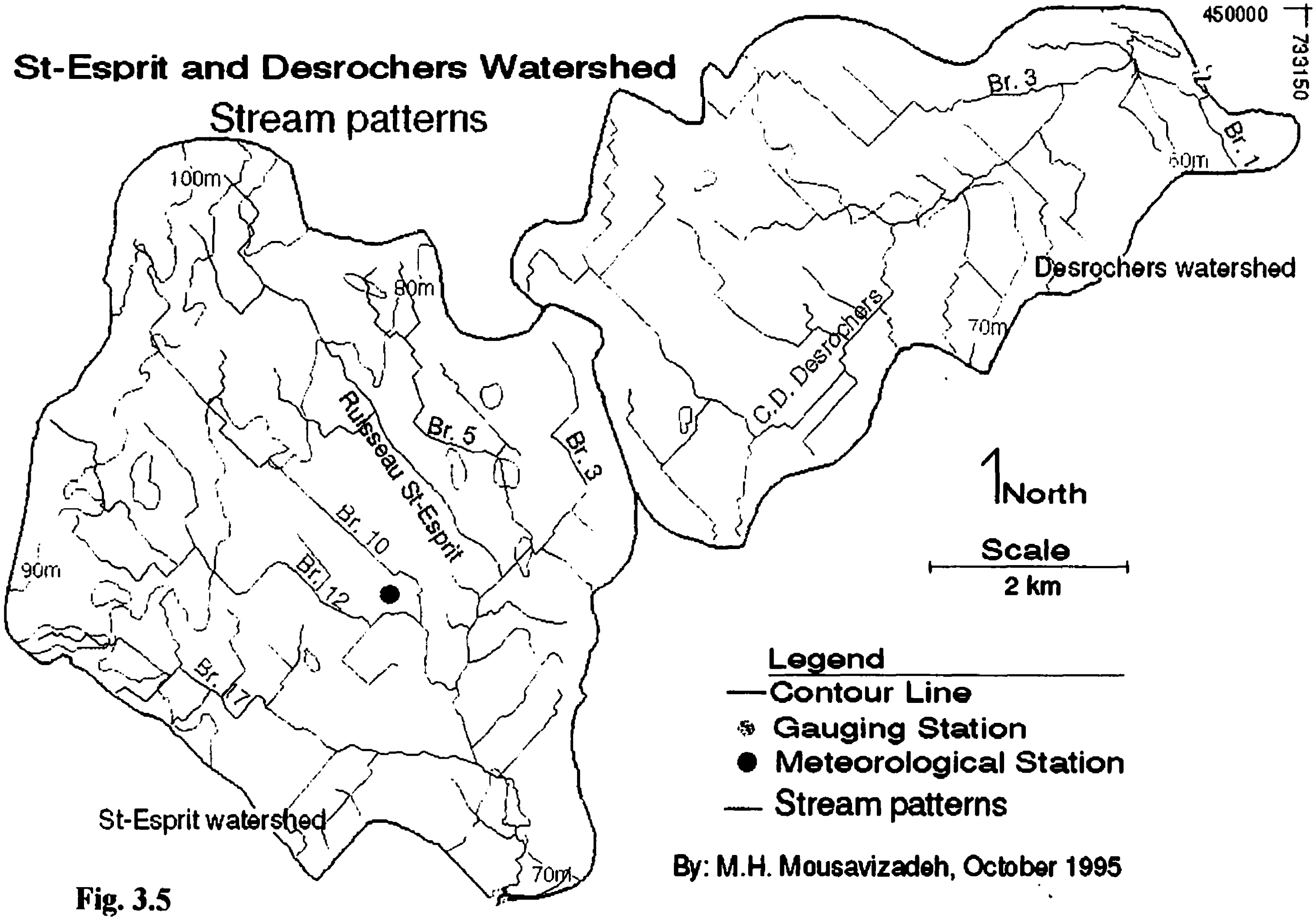

St-Esprit and Desrochers Watershed
Stream patterns
450000
733150
Br. 3
Br. 1
60m
100m
80m
Desrochers watershed
70m
C.D. Desrochers
Ruisseau St-Esprit
Br. 5
Br. 3
North
Scale
2 km
Br. 10
90m
Br. 12
Legend
Contour Line
Gauging Station
Meteorological Station
Stream patterns
Br. 17
St-Esprit watershed
70m
By: M.H. Mousavizadeh, October 1995

Fig. 3.5

Table 3.2 Distribution of Soil Textural Classes on the St. Esprit Watershed

Soil Texture	Area (ha)	Area (%)
Sand	214	8.2
Loamy Sand	147	5.7
Sandy Loam	960	36.8
Loam	117	4.5
Silty Clay Loam	80	3.1
Sandy Clay	27	1.0
Clay Loam	487	18.6
Clay	576	22.1
Total	2608	100.0

Topography can be described as flat to rolling with the majority of cultivated land having slopes of less than 3% and rarely exceeding 5%. The length of the main channel to the outlet is approximately 9 km. The watershed is characterized by a 40 m drop in elevation from its highest point to the outlet (Lapp, 1996). Slope variation on the basin is described in Figure 3.4.

The watershed's climate is temperate. Average annual precipitation, potential evapotranspiration, and temperature are 1087 mm, 572 mm, and 5.2°C, respectively (MEF, 1995).

3.2 Instrumentation

In the winter of 1993-94, a stream gauging station was established at the St. Esprit watershed outlet, and a meteorological station was installed in the basin. A map of the watershed boundary as well as the locations of the stream gauging and meteorological stations are shown in Figure 3.5.

Instrumentation for the gauging station is housed in a building (1.8 m x 2.4 m) adjacent to a culvert. The building is supplied with AC power and heat. Monitoring equipment for the station includes: a tipping bucket rain gauge, water and air temperature sensors, a water level sensor (Druck 950 submersible pressure transducer) installed on the stream bed bottom, a UDG01 ultrasonic level sensor mounted over the culvert, a datalogger (Campbell CR10) located in the gauging station building to record and store data from all instruments, and a backup system consisting of a Flowlog datalogger that independently measures water level and flow velocity and relays this data to the Campbell CR10 datalogger. The combination of independent Flowlog and water level sensors ensured the quality of the streamflow data. In-stream propeller metering of flow was also performed to ensure the general validity of the gauging station data.

The meteorological station was equipped with sensors for air and soil temperature, solar radiation, wind speed and direction, snow accumulation, as well as a tipping bucket rain gauge and a Campbell datalogger. Data collected at the McGill radar station ensured the general validity of the meteorological station data.

A rating curve was developed for the stream at the watershed outlet. Stream velocities were measured at the control section for various flow depths. Results were used to generate a rating curve that was programmed into the Campbell datalogger. Stream discharge was recorded every 10 seconds and averaged over 15 minute intervals.

American Sigma 800 SL automated water samplers were installed within the gauging stations. Sampler intake lines were suspended over the control sections to be monitored. The Sigma 800 is refrigerated and contains a carousel of 24 one-litre bottles. Automated sampling strategy was based on flow volume calculation - the automated sampler was programmed for activation at a variable but pre-determined threshold value of accumulated flow. Samples collected consisted of the automated type and the in-stream grab samples collected by individuals on weekly or bi-weekly site visits.

Further details on rating curve development and sampling strategy can be found in Lapp (1996).

3.3 Water Sampling

Water samples were analyzed for three different classes of pollutants: plant nutrients (including N, P, K, and PO_4), agricultural chemicals (including atrazine, metalachlor), and sediment. Sampling summary is shown in Table 3.3. As the sampling method became more efficient with time, less samples were taken.

Table 3.3 Water Sample Collection and Testing Summary

Year	Total Sample Number	# of Grab Samples	Number of Samples Tested for							
			NO_3	NH_4	PO_4	K	TKN	TP	Sediment	Pesticides
1994	228	61	203	203	203	203	212	203	226	158
1995	200	71	200	200	200	200	199	199	199	30
1996	155	50	155	139	155	155	98	98	155	41

Nitrogen and potassium concentrations, and total phosphorus (TP) and phosphate phosphorus (PO_4) levels were determined internally, on the Macdonald Campus. Due to the difficulties posed by accurate phosphorus level determination, TP and PO_4 concentrations were also determined by an external specialist lab; this provided a method of double-checking results. Pesticide concentrations were determined by an external laboratory specializing in agricultural chemicals analysis.

Suspended sediment concentrations of stream discharge were determined internally. Water samples of a known weight were passed through a preweighed Whatman 55 mm glass microfibre filter paper (0.5 micron) with the aid of vacuum filtration. Filter papers containing entrapped sediment were then dried for 24 hours and then reweighed.

Blank and replicate samples inserted and chosen at random were sent to both internal and external labs. This procedure provided quality control.

3.4 Hydrology and sediment data analysis

The hydrologic and water quality of the St. Esprit watershed was characterized by Lapp (1996). Flow records from the gauging station and precipitation records from the weather station were combined to characterize hydrologic events occurring in the watershed. Values for time of concentration, lag time, time to peak, and the recession constant were generated from flow records or derived using several equations such as: the SCS nomograph equation (SCS, 1972), the Kirpich, and Bransby Williams equations (Madramootoo et al., 1988).

Peak flow and surface runoff for these events were also estimated by Lapp (1996). Peak flows were calculated from the rating curve. Surface runoff was determined using a straight line method of hydrograph separation with the flow rate at the start of the runoff event being assumed to represent base flow. Approximately 50% of the watershed's cropped land is tile drained (Enright et al., 1995). Using the first derivative of the hydrograph as an indicator, Lapp (1996) separated drainflow from surface runoff by cutting the flow off approximately 3 hours after time of peak flow - that is, in general, any flow occurring 3 hours after peak flow was no longer assumed to be contributing to surface runoff, but was assumed to be originating from drainflow.

Sediment yield for the above events was similarly estimated. Using results from suspended sediment analyses performed on water samples taken before, during, and after runoff events, instantaneous sediment concentrations in the channel were determined. Suspended sediment concentrations at 15-minute intervals during the event were then calculated by linear interpolation. Overall, it was observed that suspended sediment concentrations would reach a maximum a few hours before peak flow and would then drop sharply. This general pattern was followed in sediment yield estimation; the products of sediment concentration and flow for each 15-minute interval during the runoff event were summed in order to calculate the total sediment yield for the event. The 3-hour cutoff margin was also used in sediment yield calculations.

3.5 AGNPS Model simulations

3.5.1 AGNPS initial data entry

As mentioned previously, AGNPS requires the input of certain initial data parameters. A summary of all the initial parameters required for input is shown in Table 3.4. For the purpose of this study, a storm was defined as a rainfall event producing a minimum of 1.5 mm of runoff. Since rainfall energy-intensity values (equivalent to the rainfall erosion indices in the USLE) were not known, storm duration and storm type values were entered, thereby enabling AGNPS to calculate energy-intensity values for each event. Two storm types were used: 1 and 1a. Both represent the Pacific maritime climate with wet winters and dry summers. The peak flow and geomorphic calculation toggle parameters were set to "AGNPS" and "YES", respectively. This implies that the CREAMS method of peak flow calculation (equation 3) was used, and that channel dimensions were determined through geomorphic principles and relationships (Young et al., 1994). The hydrograph shape factor toggle was set to 58% runoff prior to peak flow. This value represents the average percent runoff prior to peak as calculated for observed events using data from the gauging station.

The depth and duration of precipitation input for a given event were taken as being the rainfall accumulation occurring during the period of time most representative of the rainfall event. That is, sporadic, low intensity rainfall taking place at the very beginning or at the tail end of a rainfall event was not included in the total

Table 3.4 Initial Input Parameters for the AGNPS Model

Row Number	*Data*
	Watershed Input
1	Watershed identification
2	Cell area (acres)
3	Total number of cells
4	Precipitation (inches)
5	Storm duration
6	Storm type
7	Energy-intensity value (or 5 and 6)
8	Peak Flow Calculations (SCS-TR55/AGNPS)
9	Geomorphic Calculations (Yes/No)
10	Hydrograph Shape Factor (K Coefficient/% Runoff)

event precipitation depth, nor was the duration of this sporadic rainfall included in the total event duration. This method allowed AGNPS to calculate more representative rainfall energy-intensity values. For example, consider a hypothetical storm of 50 mm depth and 7 hours duration. AGNPS would calculate a rainfall energy-intensity value of 13.03 foot-tons per acre-inch for this event. If one were to include a hypothetical total rainfall depth of 2 mm occurring one hour prior to and one hour after the main 50 mm depth, the rainfall energy-intensity value for this 52 mm, 9-hour storm would fall to 11.8 foot-tons per square inch. It was therefore assumed that the inclusion of such sporadic rainfall would lead to an underestimate of the soil movement caused by rainfall impact.

Before determining model input parameters for AGNPS, a grid system was superimposed on the watershed area. This grid was overlaid on maps such as that of Figure 3.2. These geographic charts were drawn using GIS software and included maps depicting distributions of channel systems, slopes, soil types, and land use. A total of 295-9.25 ha cells covered the entire watershed area. Most of these cells were then subdivided to take into account the variation of model parameters within this relatively large cell size. This resulted in 974 divisions, 922 of which represented one quarter of a subdivided cell (2.3125 ha each), and the remainder of which were whole cells. The choice of this cell size is within the range of 1 to 4 ha recommended in the AGNPS User's Guide (Young et al., 1987).

3.5.2 Spreadsheet input and output parameters

The AGNPS model requires various input values for soil texture, surface condition constant, SCS curve number, etc... (Table 3.5). These values are needed for each cell and are input to a spreadsheet type editor. Watershed topography and land use characteristics were determined from aerial photography and from available land use and slope maps. The model output at the watershed outlet includes several parameters for hydrology, sediment, and chemicals (Table 3.6). A graphics utility also exists within AGNPS: it allows the user to identify individual cells, and therefore, areas, where selected watershed output parameter(s) are above or below any desired threshold values.

Table 3.5 AGNPS Model Spreadsheet Data Entry

Row Number	*Data*
	Cell Parameter
1	Cell number
2	Number of the cell into which it drains
3	SCS curve number
4	Average land slope (%)
5	Slope shape factor (uniform, convex, or concave)
6	Average field slope length (feet)
7	Average channel slope (%)
8	Average channel side slope (%)
9	Mannings roughness coefficient for the channel
10	Soil erodibility factor (K) from USLE
11	Cropping factor (C) from USLE
12	Practice factor (P) from USLE
13	Surface condition constant (based on land use)
14	Aspect (one of 8 possible directions indicating principal drainage direction)
15	Soil texture (sand, silt, clay, peat)
16	Fertilization level (zero, low, medium, high)
17	Pesticide indicator and level (indicates presence and level of pesticide input)
18	Point source indicator (indicates existence of a point source input within cell)
19	Gully source level (estimate of amount, tons, or gully erosion in a cell)
20	Chemical oxygen demand factor
21	Impoundment factor (indicates presence of impoundment terrace system)
22	Channel indicator (indicating existence of defined channel within cell)

(Source: Young et al., 1989)

Table 3.6 Output at the Watershed Outlet for each cell

Hydrology Output

Runoff volume (inches)
Peak runoff rate (cubic feet/second)
Fraction of runoff generated within the cell

Sediment Output

Sediment yield (tons)
Sediment concentration (ppm)
Sediment particle size distribution
Upland erosion (tons/acres)
Amount of deposition (%)
Sediment generated within the cell (tons)
Enrichment ratios by particle size
Delivery ratios by particle size

Chemical Output

Nitrogen
- Sediment associated mass (pounds/acre)
- Concentration of soluble material (ppm)
- Mass of soluble material (pounds/acre)

Phosphorus
- Sediment associated mass (pounds/acre)
- Concentration of soluble material (ppm)
- Mass of soluble material (pounds/acre)

Pesticide
- Sediment associated mass (pounds/acre)
- Concentration of soluble material (ppm)
- Mass of soluble material (pounds/acre)

Chemical Oxygen Demand
- Concentration (ppm)
- Mass (pounds/acre)

(Source: Young et al., 1989)

3.5.3 Selection of AGNPS model parameters for spreadsheet data entry

Using watershed maps, values for flow direction, land slope, soil texture, and land use were determined for each cell or subdivision and input to a spreadsheet. Other parameter values were determined in conjunction with, or solely through, the aid of available literature. For example, slope length is defined as the distance from the point of origin of overland flow to either the point where slope decreases to the extent that deposition begins, or the point where runoff enters a defined channel, whichever is limiting (Beasley et al., 1984). From this definition, as well as the channel system and slope maps, slope length was determined for each cell and was seen to generally vary from 30 m (100 ft.) to a maximum of 300 m (1000 ft.). Slope shape was assumed to be uniform for each cell and therefore received a value of 1.

SCS curve numbers were determined by standard methods: 5-day antecedent soil moisture conditions, hydrologic soil groups, and crop covers all combined to give

Table 3.7 Initial Curve Numbers Selected for AGNPS

Land-Use	Curve Numbers for Different Hydrologic Soil Groups and Antecedent Moisture Conditions											
	Soil Group A			Soil Group B			Soil Group C			Soil Group D		
	AMC			AMC			AMC			AMC		
	I	II	III	I	II	III	I	II	III	I	II	III
Residential	53	72	86	62	79	91	70	85	94	75	88	95
Soya/Small Grain	43	63	80	55	74	88	66	82	92	70	85	94
Hay/Pasture	30	49	69	50	69	84	62	79	91	68	84	93
Vegetables	53	72	86	64	81	92	75	88	95	80	91	97
Corn	51	70	85	63	80	91	73	87	95	78	90	96
Forest	12	25	43	35	55	74	51	70	85	59	77	89

curve numbers for individual cells as specified in Schwab et al. (1981). Curve numbers selected for use in the model are shown in Table 3.7. Values for the overland Manning's coefficient and the surface condition constant were taken from the AGNPS manual (Young et al., 1994) and varied with crop cover.

Since up and downslope farming is practiced throughout the watershed, the P or practice factor used in the USLE was assumed to be equal to 1 for all cells. Values of the K (soil erodibility) and C (cover and management) factors are summarized in Tables 3.8 and 3.9. The combined L (slope length) and S (slope steepness) factor was calculated by AGNPS using given values of slope length and percent grade.

Table 3.8 Soil Erodibility Factor K Values Selected for Input to AGNPS

Soil Type	K (tons/acre)
Sand	0.10
Sandy Loam	0.24
Fine to Very Fine Sandy Loam	0.35
Loamy Very Fine Sand to Sandy Loam	0.31
Loam	0.28
Loam to Sandy Loam	0.26
Silty Loam to Silty Clay Loam	0.37
Silty Clay Loam	0.32
Silty Clay	0.33
Clay to Clay Loam	0.27
Clay Loam	0.25
Clay	0.29

(Source: Schwab et al., 1981)

Table 3.9 Cover/Management Factor C Values Selected for Input to AGNPS

Land Use	C
Corn	0.38
Grain	0.15
Hay	0.10
Pasture	0.03
Soybeans	0.27
Vegetables	0.20
Forest	0.02
Residential	0.01

(Source: Beasley et al., 1984)

Channel characteristics were determined from profile maps obtained from MAPAQ. Spreadsheet row numbers 16-21 were assigned a value of 0 since nutrients and pesticides were not simulated, and since no significant gully erosion, point sources, or impoundments were detected within the watershed. Spreadsheet based software aided in the organization and manipulation of the data above. A standard

AGNPS 5.0 data input file was thus created.

3.6 AGNPS Model Calibration and Validation

Rainfall/runoff events from 1994 were used to calibrate AGNPS since they represented a relatively wide range of rainfall and antecedent moisture content characteristics. Events from 1995 and 1996 were used to validate the model. The curve number was the only parameter varied for surface runoff calibration since it is the single AGNPS spreadsheet input parameter that influences runoff. In order to calibrate sediment yield, the C factor in the USLE was varied throughout the growing season. The slope length. K, and P factors remained unaltered. The curve number and C factor were varied for each input cell. The hydrograph shape factor in the initial data screen of AGNPS was the only other factor varied since it was observed to have great influence on sediment yield.

Curve numbers were proportionally adjusted from their initial values. The C factor witnessed a similar seasonal adjustment, while the very sensitive hydrograph shape factor was varied by only a few percentage points. Characteristics of events used in the calibration and validation of AGNPS are summarized in Tables 3.10 and 3.11. Estimated values do not represent AGNPS model predictions but are those calculated from observed data.

The antecedent precipitation index was calculated for each event, and was used as a soil moisture indicator. Precipitation occurring on day 0 (within 24 hours prior to the start of the event)was incorporated into the API by using an exponent of n=0 with respect to the constant, k. A relationship between curve number and API was established. Calibration results with respect to curve numbers and C factors can be found in Appendix 1. Data for events used in model validation were estimated in precisely the same manner as those used for calibration with one exception. The API for the event of November 9, 1996 includes precipitation beyond the suggested 14-day antecedent interval. It was assumed that the heavy rainfall of October 21-23 had an influence on the initial soil moisture at the start of the November 9 event.

Table 3.10 Rainfall/Runoff Data Used in AGNPS Model Calibration

Event	Observed			Estimated		
	Rainfall Depth (mm)	Duration (hours)	Peak Flow (m^3/s)	API (mm)	Surface Runoff (mm)	Sediment Yield (tonnes)
	Weather Station Data		Outlet			
June 13/94	24	5.5	3.28	30	1.94	12.9
June 25/94	47	7.5	4.01	20	4.14	33.6
June 27/94	39	4	12.13	59	9.68	84.3
June 29/94	20	3.5	5.25	72.5	3.24	15.2
Aug. 2/94	43	6.5	3.46	22	3.55	10.1
Aug. 5/94	19	5	2.75	44	2.40	4.2
Nov. 1/94	52	26.5	1.06	3	1.84	5.9

Table 3.11 Rainfall/Runoff Data Used in AGNPS Model Validation

Event	Parameter					
	Rainfall Depth (mm)	Duration (hours)	Peak Flow (m^3/s)	API (mm)	Surface Runoff (mm)	Sediment Yield (tonnes)
	Averaged Data		Outlet			
Oct. 6/95	54	30	0.98	8	2.25	8.2
Oct. 22/95	39	8	2.36	15	2.05	23.8
Nov. 2/95	33	13	2.73	20	2.80	15.6
Oct. 21/96	82	30	7.07	5	9.13	70.0
Nov. 9/96	99	28	17.13	14[a]	28.9	247.6

a - API calculated with antecedent rainfall beyond n =14 day interval included (i.e., event of October 21-23, n = 15-17)

4.0 RESULTS AND DISCUSSION

4.1 AGNPS Model Calibration

4.1.1 Initial results

Initial AGNPS simulations used the three antecedent moisture conditions described by the SCS curve number method. A listing of the curve numbers selected for each antecedent moisture and crop cover condition on the basin can be found in Table 3.7. Table 4.1 shows the results of six initial storm simulations.

It can be seen that the events of June 13 and 25, 1994 were adequately simulated with respect to surface runoff, with errors of 18, and 8%, respectively. Runoff volumes of 2.29, and 3.81 mm were predicted as compared to observed runoff depths of 1.94, and 4.14 mm, respectively. These events were simulated under antecedent moisture condition II. Simulated peak flows were comparable to observed values (3.51, and 5.59 m^3/s as compared to 3.28, and 4.01 $^3m/s$, respectively). However, sediment yield prediction did not fare as well; 15.6, and 73.2 tonnes predicted versus 12.9, and 33.6 tonnes observed, respectively.

The storm of June 27 1994 yielded the greatest amount of observed runoff (9.68 mm). Using AMC III, AGNPS predicted 19.56 mm of surface runoff. This represents an error of more than 100%. Similarly, a peak flow of 27 m^3/s was predicted for the event as compared to 12.13 m^3/s observed (an error of 123%). The model estimated sediment yield to be 99.2 tonnes, approximately 18% more than the 84.3 tonnes observed. However, it must be kept in mind that this relatively accurate sediment yield prediction resulted from a gross overestimation of surface runoff.

The other AMC III event of June 29 yielded somewhat better results. Surface runoff was simulated as 5.33 mm compared to an observed of 3.24 mm. A peak flow estimate of 7.95 m^3/s was simulated by AGNPS for an observed value of 5.25 m^3/s. A sediment yield of 25.7 tonnes was predicted as compared to an observed yield of 15.2 tonnes. However, these results still represent errors of 64.5, 51.4, and 68.8% for surface runoff, peak flow, and sediment yield predictions, respectively.

The storm of August 2, the only event simulated under AMC I, was predicted

Table 4.1 Initial AGNPS Simulation Results Using SCS Antecedent Moisture Conditions

Event	Observed					Predicted			Error (%)			
	Rainfall Depth (mm)	Antecedent Moisture Condition	Peak flow (m^3/s)	Surface Runoff (mm)	Sediment Yield (tonnes)	Peak flow (m^3/s)	Surface Runoff (mm)	Sediment Yield (tonnes)	Peak flow	Surface Runoff	Sediment Yield	Mean
June 13/94	24	AMC II	3.28	1.94	12.9	3.51	2.29	15.6	7.0	18.0	20.7	15.2
June 25/94	47	AMC II	4.01	4.14	33.6	5.59	3.81	73.2	39.4	8.0	118.0	55.1
June 27/94	39	AMC III	12.13	9.68	84.3	27.00	19.56	99.2	122.6	102.1	17.7	80.8
June 29/94	20	AMC III	5.25	3.24	15.20	7.95	5.33	25.7	51.4	64.5	68.8	61.6
Aug 2/94	43	AMC I	3.46	3.55	10.1	3.17	2.03	46.2	8.4	42.8	358.8	136.7
Aug 5/94	19	AMC II	2.75	2.40	4.3	1.89	1.27	12.7	31.3	47.1	195.1	91.2
Average									47.1	43.4	129.9	73.6
CP'_A						3.73	2.66	0.74				2.38

to yield 2.03 mm of runoff, 46.2 tonnes of sediment, and a peak flow of 3.17 m^3/s, compared to observed values of 3.55 mm, 3.46 m^3/s, and 10.1 tonnes, respectively. These results represent errors ranging from 8.4% for surface runoff, to 358.8% for sediment yield.

The final event considered, that of August 5, 1994, was simulated by AGNPS to produce 1.27 mm of runoff, 12.7 tonnes of sediment, and a peak flow of 1.89 m^3/s. Observed values were of 2.40 mm, 4.3 tonnes, and 2.75 m^3/s. Once again, sediment yield was grossly overestimated by 195.1%, while surface runoff and peak flow were more accurately predicted to within 47.1, and 31.3%, respectively..

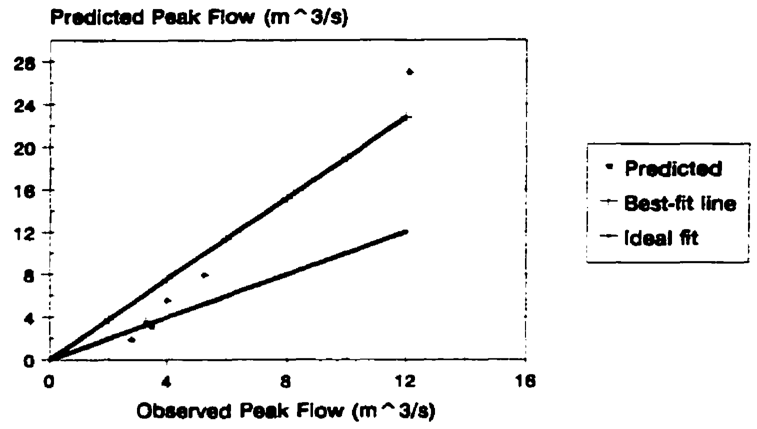
Observed and predicted parameters were compared using the coefficient of performance CP'_A (James et al., 1982) which is often used in the evaluation of simulated hydrologic parameters:

$$CP'_A = \sum_{j=1}^{n} (S(i) - O(i))^2 / \sum_{j=1}^{n} (O(i) - O_{avg})^2 \qquad \{4.1\}$$

where O(i) is the *ith* observed parameter, O_{avg} is the mean of the observed parameters, S(i) is the *ith* simulated parameter, and n is the total number of events. The coefficient of performance approaches zero as observed and predicted values get closer. Overall, CP'_A's for surface runoff, peak flow, and sediment yield were calculated as being 2.66, 3.73, and 0.74, respectively. Therefore, using this statistical parameter as an indicator, sediment yield was the parameter generally best predicted, followed by surface runoff, and peak flow. However, despite this fact, sediment yield prediction also produced the highest average percent error for the 6 events (129.9%). Average error for surface runoff and peak flow were comparable (43.4, and 47.1%, respectively).

Figures 4.1 to 4.3 display graphs of predicted versus observed hydrologic parameters. The "ideal fit" line with a slope of 1 represents a perfect one to one correlation while the "best fit curve" represents a linear regression of the predicted data points with a y-intercept of 0. The best-fit line for peak flow has a slope of 1.9 (Fig. 4.1). Identical regression lines for surface runoff and sediment (Figs. 4.2 and 4.3) have slopes of 1.33, and 1.36, respectively. These values are indicative of the fact

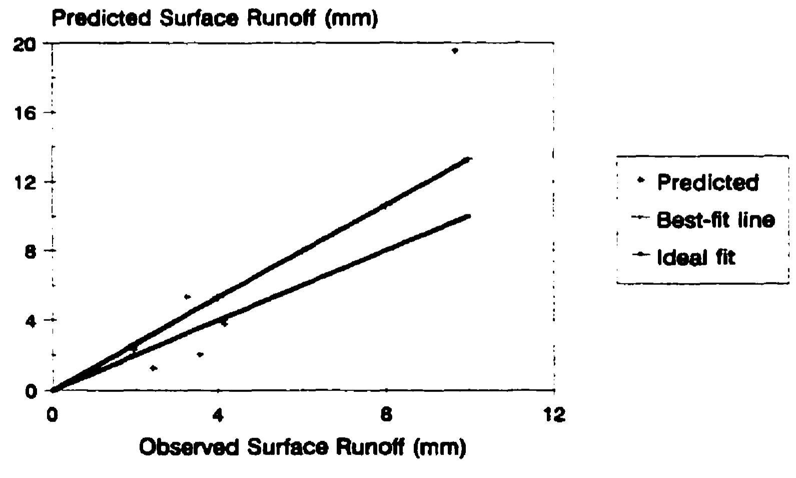
Fig. 4.1. Initial Results: Predicted vs. Observed Peak Flow



Slope of best-fit line = 1.9

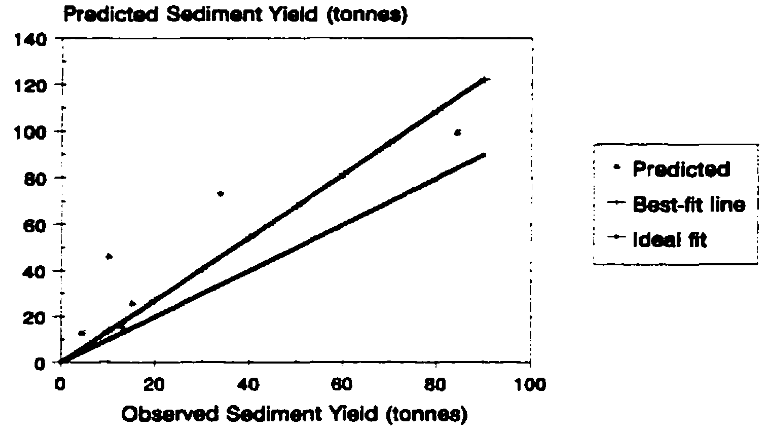
that sediment yield was constantly overpredicted, though to varying degrees. Peak flow was overpredicted by an average of 55.1% for four of the six events. Similarly, no clear pattern was observed with respect to surface runoff prediction for any of the three antecedent moisture conditions. It was therefore proposed that the AGNPS

Fig. 4.2. Initial Results: Predicted vs. Observed Surface Runoff



Slope of best-fit line = 1.33

Fig. 4.3. Initial Results: Predicted vs. Observed Sediment Yield



Slope of best-fit line = 1.36

model be calibrated by proportionally altering curve numbers through trial and error in order to provide better simulations. A relationship between curve number and antecedent precipitation index was proposed. Since sediment yield was so poorly predicted for several events, the C factor in the USLE equation was similarly altered.

4.1.2 Calibration results

All six rainfall-runoff events used in the initial simulation were used to calibrate AGNPS. In addition, another event was added (November 1, 1994) in order to include a simulation at the extreme low end of the antecedent precipitation index, i.e., an API of 3 mm. Results of the calibration are presented in Table 4.2. A complete listing of curve numbers and C factors can be found in Appendix 1. It must also be stated that best results were obtained with the %-runoff-prior-to-peak-flow initial data parameter set at 56% as opposed to its original setting of 58%. There will be more discussion of this parameter in section 4.2.

As expected, final calibration results represented an improvement on the initial simulations. Surface runoff estimation witnessed the greatest improvement with the coefficient of performance decreasing from 2.66 to 0.12, and the average percent error decreasing from 43.4 to 6.2%. Sediment yield prediction also improved considerably. The CP'_A and average percent error for sediment yield decreased from 0.74 to 0.05, and from 129.9 to 38.9%. Peak flow estimates experienced the weakest improvements with the CP'_A decreasing considerably from 3.73 to 0.43, and the mean percent error rising slightly from 43.4 to 44.3%.

On an individual basis, the events best simulated were those of June 29, and 13, with an average percent error of 7.0, and 7.3, respectively, for the three parameters concerned. Surface runoff was predicted to within 1.9% for the June 29 storm; sediment yield was estimated to within 2.3% for the June 13 storm. The August 5 storm was simulated with an average error of 13.9%, with surface runoff predicted with only 4.6% error.

Three events were simulated with average errors between 20 and 30%. June 25, 27, and August 2 storms were on average off by 21.5, 24.6, and 28.9%. The first event resulted in error of only 1.9% for surface runoff, but a 53.6% error for peak flow. Errors for the June 27 storm were more consistent and ranged between 11.4, and 38.9% for sediment yield and peak flow, respectively. However, it is important to note that this relatively accurate sediment yield prediction was achieved by allowing channel scouring for all particle sizes and choosing a storm type of 1 in the simulation; this increased sediment yield. Since this storm produced a high peak flow of more than 12 m^3/s, both these assumptions were deemed valid. Parameter prediction was highly variable once again for the August 5 storm with runoff being predicted to within 0.3% while peak flow was off by more than 50%. On an individual basis, the events best simulated were those of June 13, and 29, with average percent errors of 7.3, and 7.0, respectively, for the three parameters concerned.

Table 4.2 AGNPS Model Calibration Results

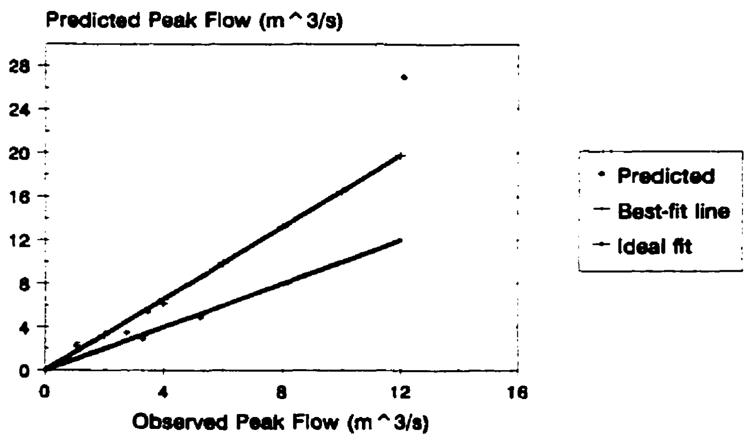
Event	Observed						Predicted			Error (%)			
	Rainfall Depth (mm)	Duration (hours)	API (mm)	Peak flow (m^3/s)	Surface Runoff (mm)	Sediment Yield (tonnes)	Peak flow (m^3/s)	Surface Runoff (mm)	Sediment Yield (tonnes)	Peak flow	Surface Runoff	Sediment Yield	Mean
June 13/94	24	5.5	30	3.28	1.94	12.9	2.91	1.78	12.6	11.3	8.3	2.3	7.3
June 25/94	47	7.5	20	4.01	4.14	33.6	6.16	4.06	36.6	53.6	1.9	8.9	21.5
June 27/94	39	4	59	12.13	9.68	84.3	16.85	11.94	83.9[a]	38.9	23.4	11.4	24.6
June 29/94	20	3.5	72.5	5.25	3.24	15.2	4.91	3.30	13.3	6.5	1.9	12.5	7.0
Aug. 2/94	43	6.5	22	3.46	3.55	10.1	5.46	3.56	13.0	57.8	0.3	28.7	28.9
Aug. 5/94	19	5	44	2.75	2.40	4.3	3.44	2.29	4.7	25.1	4.6	11.9	13.9
Nov. 1/94	52	26.5	3	1.06	1.84	5.9	2.3	1.78	17.5	117.0	3.3	196.6	105.6
Average										44.3	6.2	38.9	29.8
CP'_A							0.12	0.05	0.43				0.2

a - sediment yield predicted with channel scouring for all particle sizes and storm type 1

The event of November 1 was the most poorly simulated. A mean error of 105.6% was produced for this simulation. Although surface runoff was off by only 3.3%, peak flow and sediment yield predictions were off by 117.0, and 196.6%, respectively. However, the gross error in peak flow estimation represented an underestimate of only 1.24 m^3/s between the observed value of 1.06 m^3/s, and the predicted value of 2.3 m^3/s. The large error in sediment yield prediction can be attributed to the event's long duration (26.5 hours) coupled with the fact that the event occurred in late fall. Cold temperatures may have resulted in partial freezing of the soil surface thereby inhibiting the relatively low energy of the storm to dislodge and erode soil particles from the surface as easily as would normally be expected.

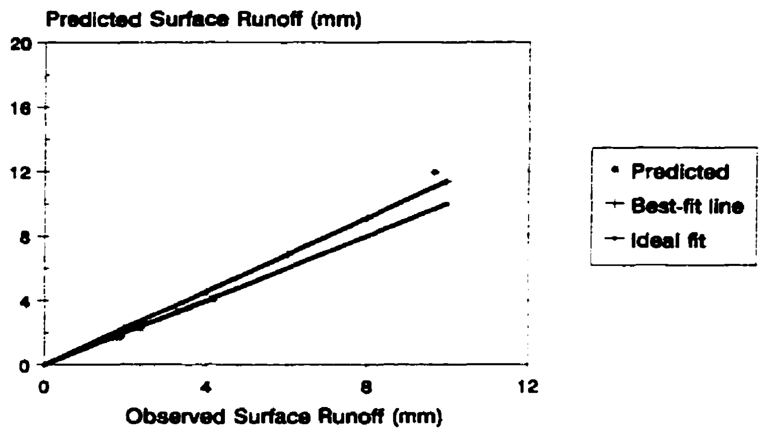
In comparison to the initial simulations, linear regressions of observed and predicted parameters improved. The slope of the predicted versus observed peak flow line decreased from 1.9 to 1.65 (Fig. 4.4). Though this does represent an improvement, the change is somewhat marginal and indicates that peak flow still tends to be overpredicted by AGNPS. Predicted versus observed surface runoff and sediment yield regression lines demonstrated greater relative improvements with slopes falling from 1.33 to 1.14, and 1.36 to 1.02, respectively (Figs. 4.5 and 4.6).

Fig. 4.4. Calibration Results: Predicted vs. Observed Peak Flow



Slope of best-fit line = 1.65

Fig. 4.5. Calibration Results: Predicted vs. Observed Surface Runoff

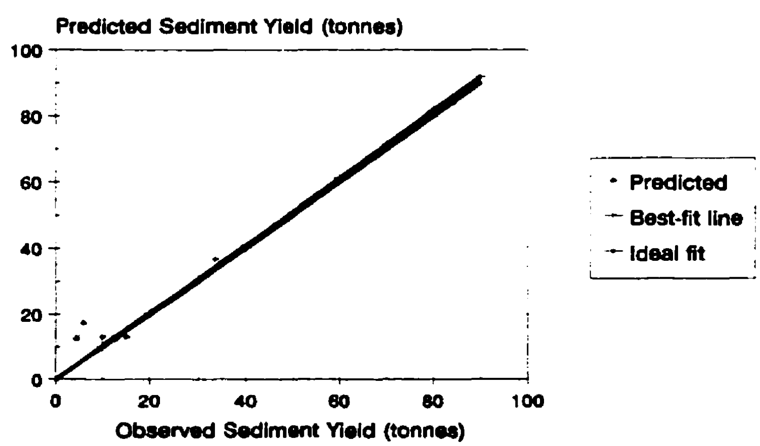


Slope of best-fit line = 1.14

Both these values are close to the ideal slope of 1.

As previously mentioned, a relationship between the SCS curve number and API was developed for each of the four SCS hydrologic soil groups and the five general land-use conditions (residential, forested, row crops, hay, grain). This resulted in twenty calibration curves that represent antecedent soil moisture as a continuous

Fig. 4.6. Calibration Results: Predicted vs. Observed Sediment Yield



Slope of best-fit line = 1.02

Fig. 4.7 CN vs. API: Residential/Soil Type A

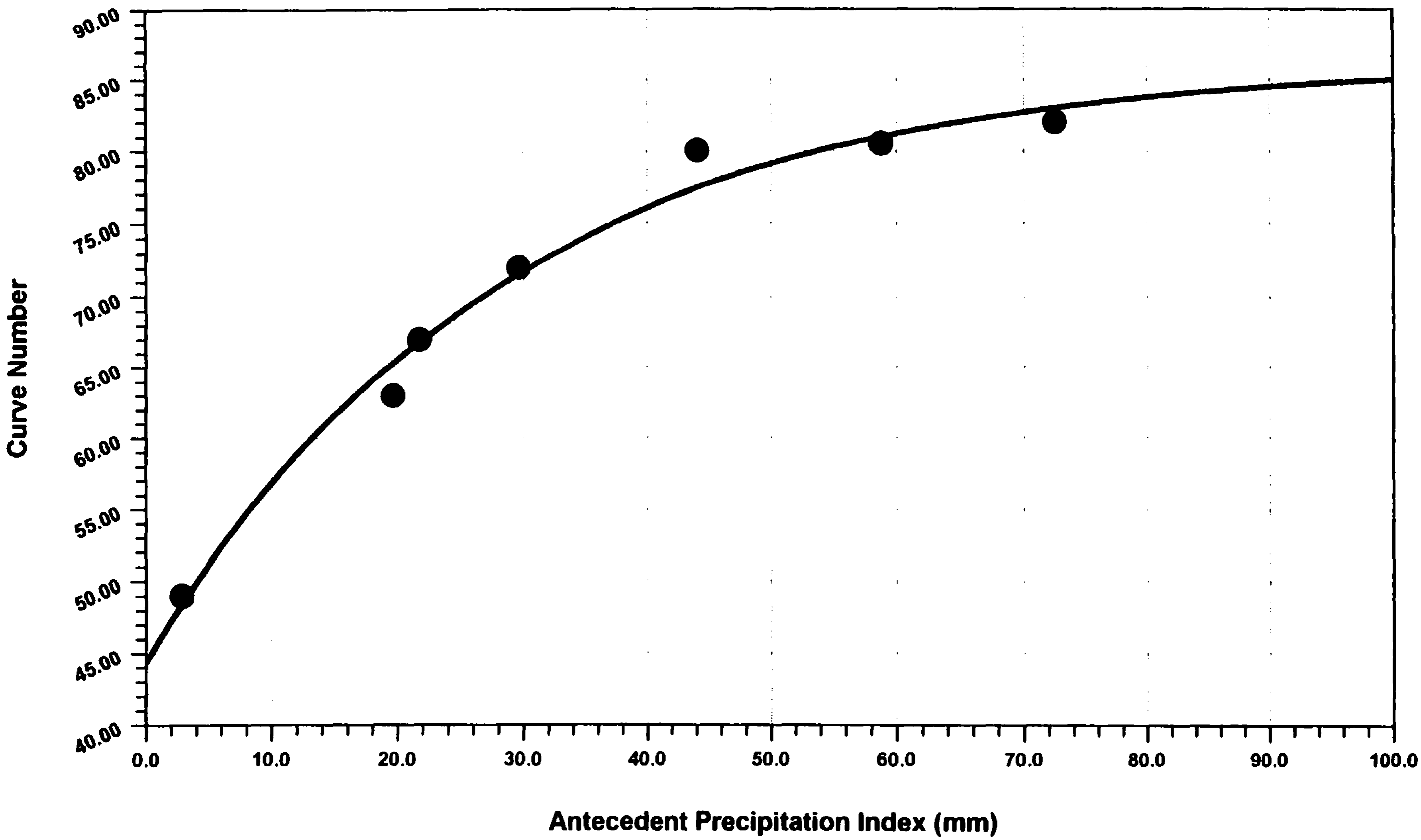


Fig. 4.8 CN vs. API: Grain/Soil Type B

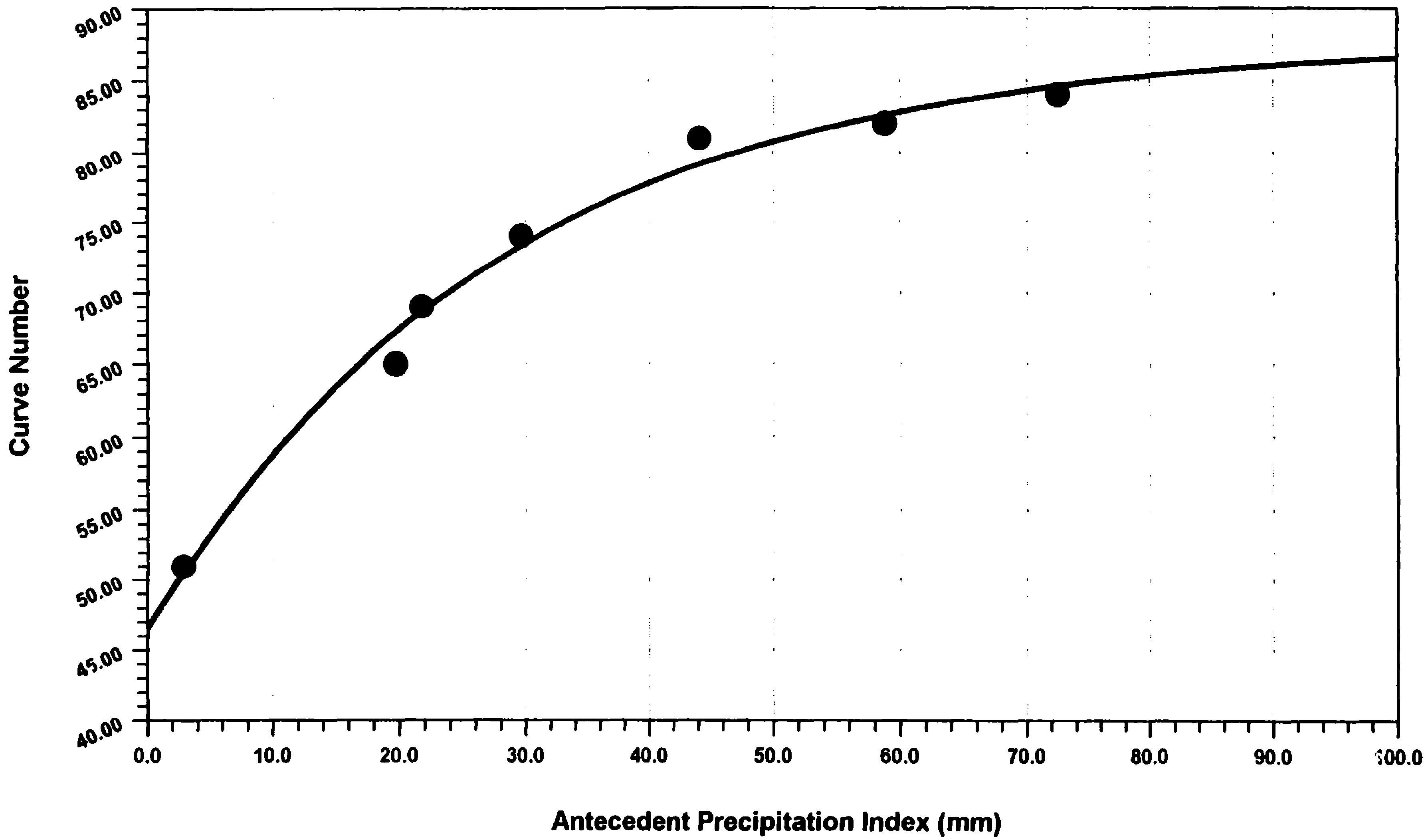


Fig. 4.9 CN vs. API: Pasture/Soil Type C

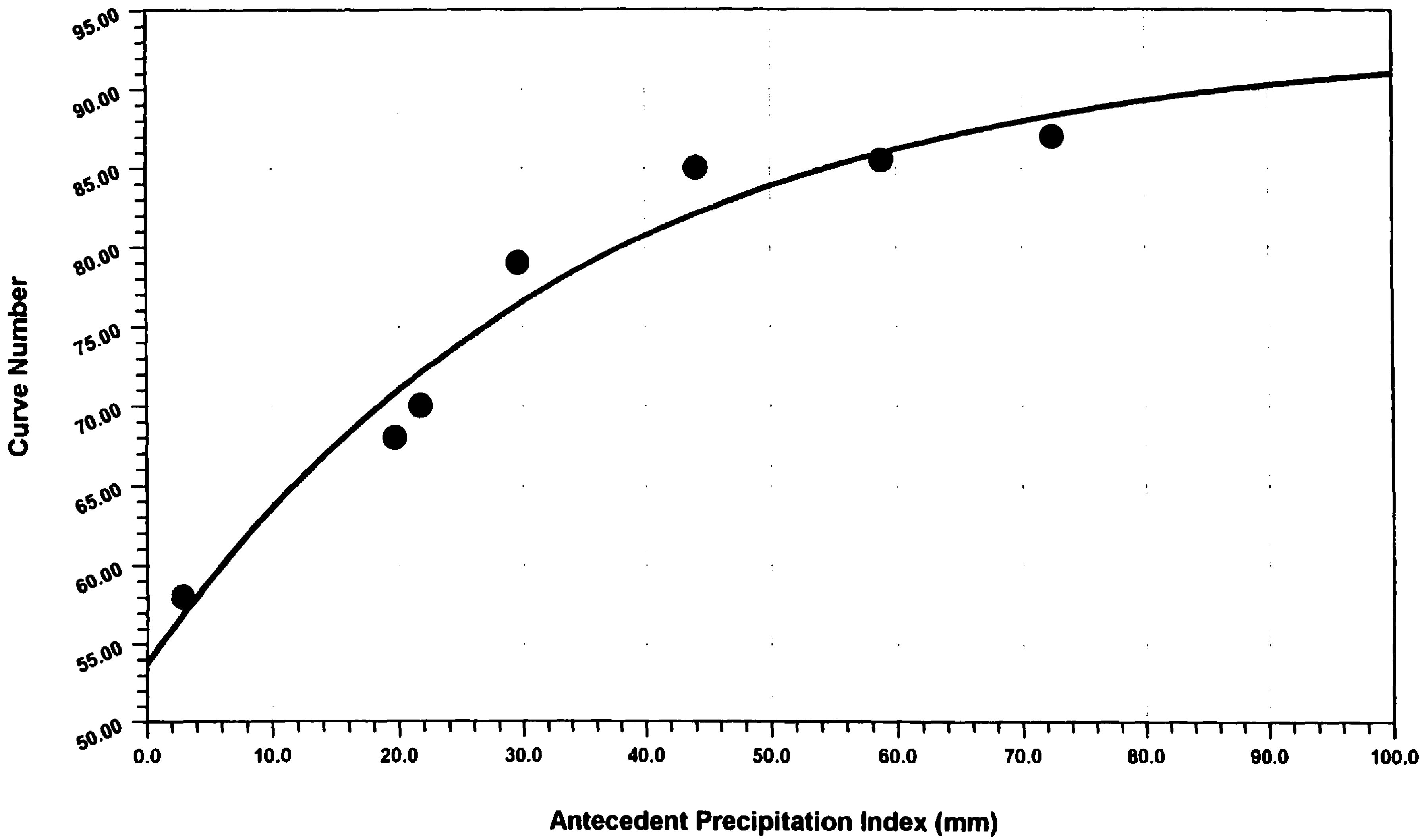


Fig. 4.10 CN vs. API: Row Crops/Soil Type D

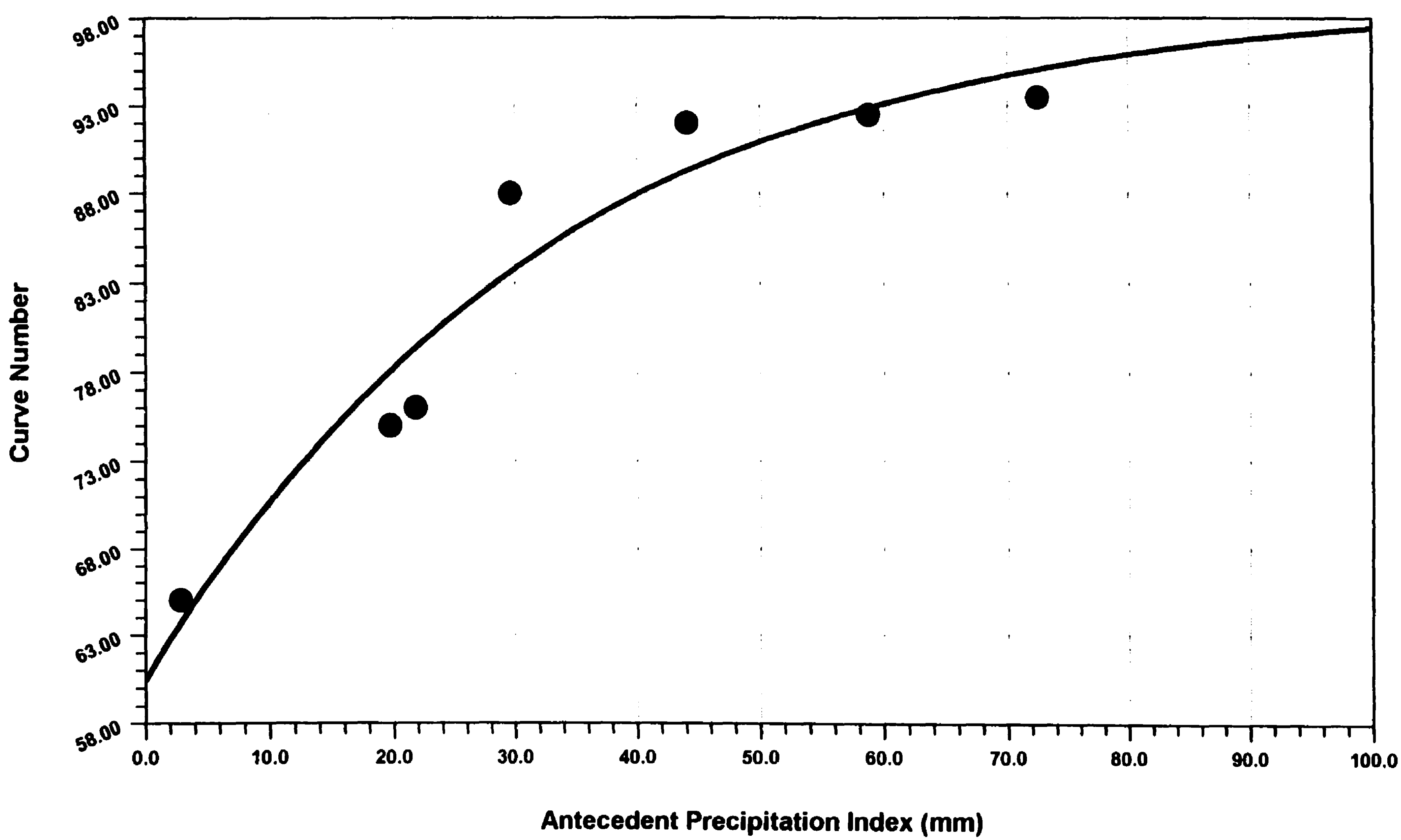
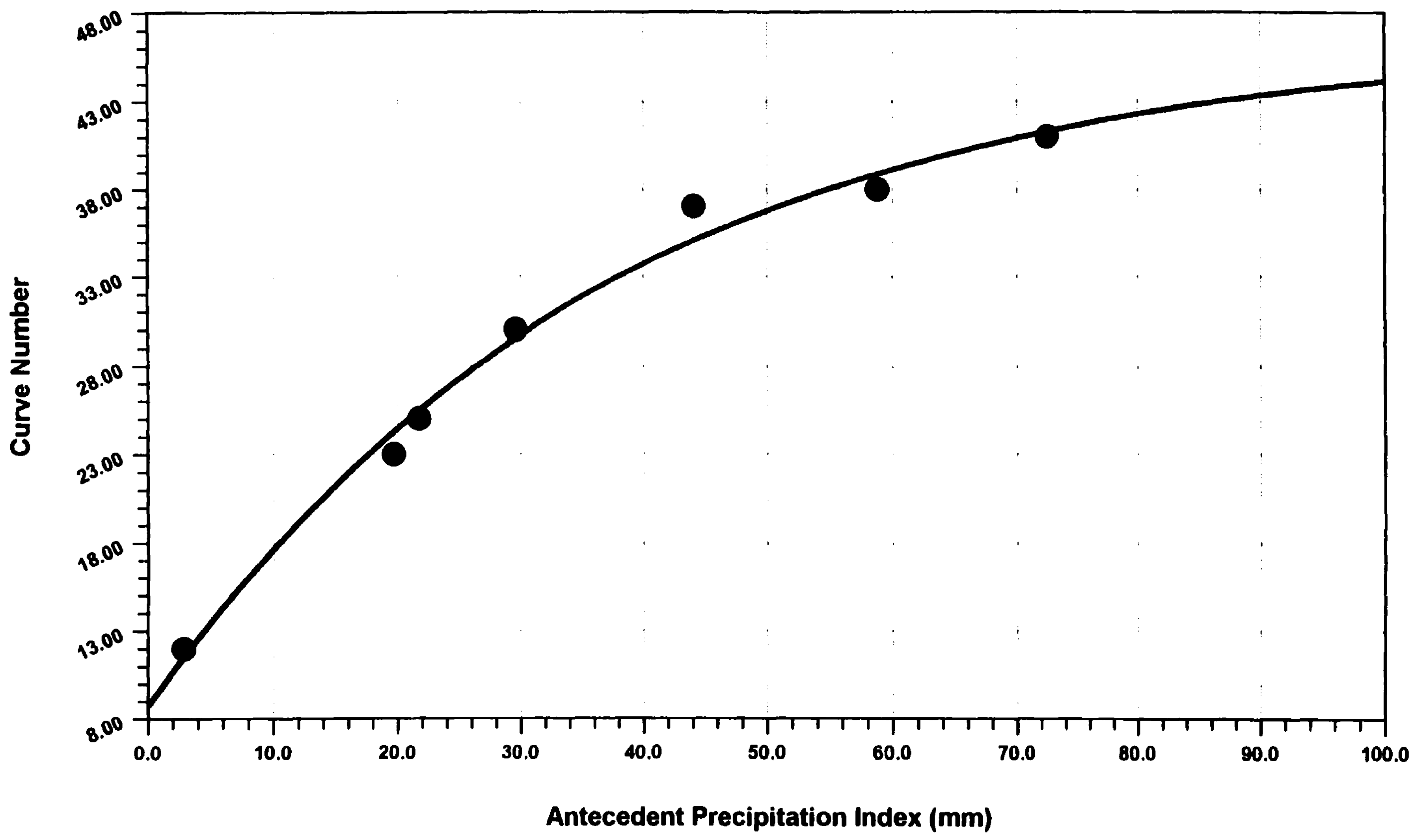


Fig. 4.11 CN vs. API: Forest/Soil Type A



parameter. These curves enable curve number selection for each input cell in the AGNPS model. Figures 4.7 to 4.11 are examples of calibration curves developed in this manner. Graphs of all twenty curves can be found in Appendix 1.

These best-fit curves generally yielded correlation coefficients (r-values) of 0.95 or greater. Although correlation values are artificially high due to the naturally narrow range of curve number variation, it would nevertheless seem that the calibration curves produced are as reasonable and good as can be expected. All twenty curves follow the same general pattern of exponential decay with curve number rising sharply as the API increases from 0 to 30 mm. Curve numbers then begin to level off as the API reaches the 40 and 50 mm range, and eventually approaches 100 mm where the CN remains essentially constant.

In order to test the validity of these calibration curves, curve numbers were selected from the graphs for a different set of rainfall-runoff events of a known API. Results of this validation are presented in the following section.

4.1.3 Validation results

Five rainfall-runoff events were used in the validation of AGNPS. Curve numbers were selected using the calibration curves discussed in the previous section. Validation results are presented in Table 4.3.

Overall, coefficients of performance for surface runoff and sediment yield were comparable to those calculated in model calibration (0.01, and 0.02, respectively). However, the CP'_A for peak flow rose to 2.07 compared to 0.43 for calibration. Mean percent error for all parameters and events was greater for validation (50.9%) than for calibration (29.8). A large portion of this error was due to the poorly modeled event of October 6, 1995, combined with the general inability of AGNPS to predict peak flow.

The storms of October 22, 1995 and October 21, and November 9, 1996 were the best simulated events. Surface runoff and sediment yield were predicted to within 3.0, and 1.7%, respectively, for the large October 22, 1996 storm. The other large storm, that of November 9, 1996, was simulated with comparable accuracy with surface runoff and sediment yield predicted to within 11.1, and 7.8%, respectively. It is important to note that the accurate sediment yield prediction for the October 21 storm was achieved by allowing channel scouring of all particle sizes in the simulation. Though the observed peak flow for this event (7 m^3/s) was relatively high, it cannot be ascertained whether the channel scouring assumption is valid. Similarly, the good sediment yield prediction for the November 9, 1996 event was achieved by allowing channel scouring of all particle sizes and assuming a storm type of 1. In this case, This increase in API essentially represented the assumption that part of the heavy rainfall that began on October 21 contributed some soil moisture prior to the November 9 storm. The relatively low evapotranspiration rates experienced during this time period would tend to support this assumption. The October 22, 1995 storm was also adequately modeled with surface runoff and sediment yield estimates producing errors of 13.2, and 10.1%, respectively. Although, predicted peak flow was off by 21.2% for this event, the two heavy storms of October 21, and November 9 produced peak flow simulation errors of 90.7, and 103.9%.

In comparison to the three storms described above, the events of October 6, and November 2, 1995 were poorly modeled. Surface runoff and sediment yield for the October 6 storm were predicted to within 35.6, and 20.7%. However, peak flow was grossly overestimated by 359.2%. This extreme error can be attributed to the fact that the October 6 event was a complex storm with rainfall increasing and tapering off at intervals. This storm pattern coupled with a low initial stream flow (0.15 m^3/s) did not allow flow to increase to any sharp degree, and yielded a peak flow of only 1.06 m^3/s. Both these factors cannot be taken into account by AGNPS. The November 2 event was simulated with similar accuracy, with runoff and sediment yield predictions witnessing errors of 45.7, and 25.6%, respectively. Though peak flow estimate for this event was underpredicted by only 13.9%, it must be kept in mind that the underestimate of surface runoff (1.52 mm compared to 2.8 mm observed) made this small error possible. Since these two parameters are related, a more accurate surface

Table 4.3 AGNPS Model Validation Results

Event	Observed						Predicted			Error (%)			
	Rainfall Depth (mm)	Duration (hours)	API (mm)	Peak Flow (m^3/s)	Surface Runoff (mm)	Sediment Yield (tonnes)	Peak flow (m^3/s)	Surface Runoff (mm)	Sediment Yield (tonnes)	Peak flow	Surface Runoff	Sediment Yield	Mean
Oct. 6/95	54	30	8	0.98	2.25	8.2	4.5	3.05	9.9	359.2	35.6	20.7	138.5
Oct. 22/95	39	8	15	2.36	2.05	23.8	2.86	1.78	21.4	21.2	13.2	10.1	14.8
Nov. 2/95	33	13	20	2.73	2.80	15.6	2.35	1.52	11.6	13.9	45.7	25.6	28.4
Oct. 21/96	82	30	5	7.07	9.13	70.0	13.48	9.4	71.2[a]	90.7	3.0	1.7	31.8
Nov. 9/96	99	28	14[b]	17.13	28.9	247.6	34.92	25.7	228.2[c]	103.9	11.1	7.8	40.9
Average										117.8	21.7	13.2	50.9
CP'_A							2.07	0.02	0.01				0.7

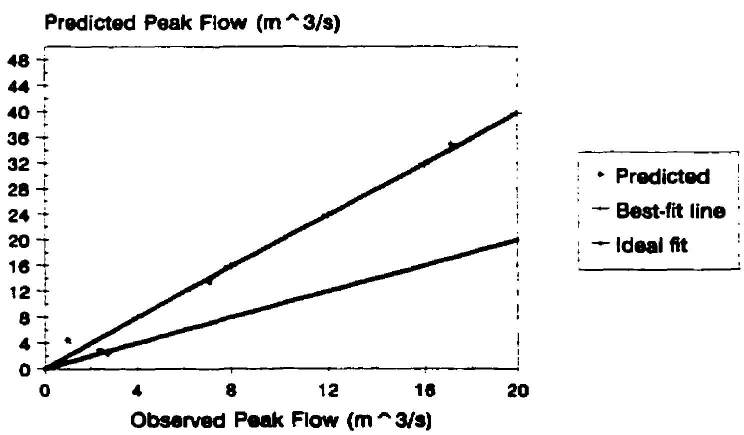
a - sediment yield predicted with channel scouring for all particle sizes

b - API calculated with antecedent rainfall beyond n =14 day interval included (i.e., event of October 21-23, n = 15-17)

c - sediment yield predicted with channel scouring for all particle sizes and storm type I runoff prediction would probably have resulted in an overestimate of peak flow similar to those witnessed in the simulation of other events. Inaccuracies in runoff and sediment estimates for this November event may once again be due to partial freezing or crusting of the soil surface which may have decreased soil permeability and erosivity. It should be stated that the November 9, 1996 event occurred during unusually mild weather conditions for that time of year. This fact may have made it possible for AGNPS to model the event successfully since soil freezing was not a factor.

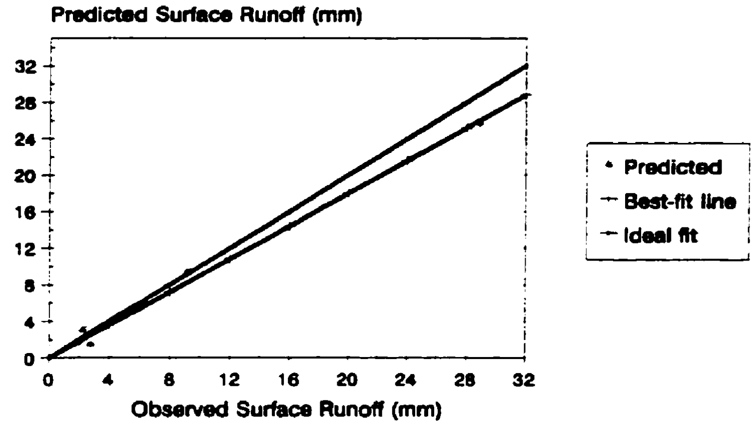
Regression line slopes of predicted versus observed parameters for model validation were comparable to those of model calibration. The slope of the peak flow best-fit line increased from 1.65 to 1.99 (Fig. 4.12) once again indicating the general tendency of AGNPS to overpredict peak flow. The value of 1.99 is also comparable to that obtained for initial simulations (1.9). It would therefore seem that no improvements were made with respect to peak flow prediction. Regression line slopes for surface runoff and peak flow were of 0.9, and 0.93, respectively (Figs. 4.13 and 4.14). These values are once again close to 1 and are comparable to the slopes obtained for model calibration regressions. The improvement in surface runoff and

Fig. 4.12. Validation Results: Predicted vs. Observed Peak Flow



Slope of best-fit line = 1.99

Fig. 4.13. Validation Results: Predicted vs. Observed Surface Runoff

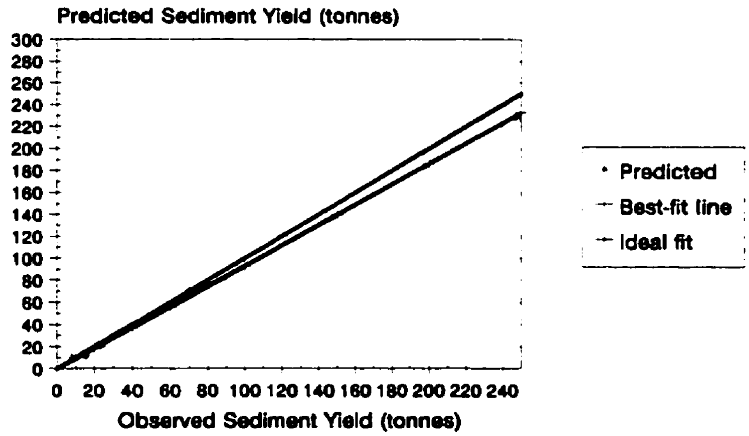


Slope of best-fit line = 0.9

sediment yield prediction with respect to the initial simulations therefore seems to have been maintained.

Although modeling of the study watershed using AGNPS was limited by the amount of documented events available for simulation, the modeled events do suggest some general patterns. The simulation of rainfall-runoff events at the St. Esprit Water-

Fig. 4.14. Validation Results: Predicted vs. Observed Sediment Yield



Slope of best-fit line = 0.93

shed with respect to relative surface runoff and sediment yield prediction can be successfully achieved using AGNPS. Successful modeling requires use of API and associated curve numbers. The CREAMS equation used to estimate peak flow in AGNPS consistently overestimates this parameter.

4.2 AGNPS Sensitivity Analysis

A sensitivity analysis was performed on the AGNPS model to determine which input parameters have the greatest influence on simulation results. Input parameters considered include API and associated curve numbers, USLE K, C, and P factors, Manning's roughness coefficient, and the surface condition constant. The hydrograph shape factor entered in the initial data section of AGNPS was the only other factor considered. The sensitivity analysis was performed for each validation event by varying each of the above parameters by plus or minus 25, 50, and 100%, in separate simulations, and then calculating the percent change in output parameters. The surface condition constant and Manning's n were observed to have negligible influence on simulation results. Therefore, sensitivity of these parameters is not discussed.

4.2.1 API and related curve number sensitivity

Antecedent precipitation index and, therefore, curve number sensitivity is documented in Table 4.4. API and curve number variation were observed to have considerable influence on surface runoff and peak flow simulation results. Sediment yield was relatively less sensitive to API variation. These results were consistent in both positive and negative API variation. For example, a 25% decrease in API for all five events resulted in an average decrease of 30% for surface runoff, and 27.8% for peak flow. A 25% increase in API resulted in increases of 28.4, and 27.8%, for surface runoff, and peak flow, respectively. However, these same variations resulted in average decreases, and increases of 12.4, and, 10.0%, respectively, for sediment yield. As expected, the higher order variations (± 50, 100%) resulted in proportionately greater changes in output parameters (with the exception of sediment

Table 4.4 Runoff, Sediment Yield, Peak Flow Sensitivity With API Variation

Parameter	API Variation (%)	Oct. 6/95	Oct. 22/95	Nov. 2/95	Oct. 21/96	Nov. 9/96	Average Variation (%)
		Initial API (mm)					
		8	15	20	5	14	
		Parameter Yield (Percent Change from Zero Variation)					
Surface Runoff (mm)	0	3.05 (0)	1.78 (0)	1.52 (0)	9.40 (0)	25.70 (0)	0.0
	-25	2.03 (-33)	1.02 (-43)	0.76 (-50)	8.64 (-8)	21.59 (-16)	-30.0
	+25	3.56 (17)	2.79 (57)	2.29 (51)	9.91 (5)	28.70 (12)	28.4
	-50	1.78 (-42)	0.76 (-57)	0.25 (-84)	8.13 (-14)	18.80 (-27)	-44.8
	+50	4.06 (33)	3.30 (85)	4.57 (201)	11.68 (24)	31.50 (23)	73.2
	-100	0.76 (-75)	0.04 (-98)	0.00 (-100)	5.59 (-41)	10.41 (-59)	-74.6
	+100	5.59 (83)	7.11 (299)	7.87 (418)	13.2 (40)	44.45 (73)	182.6
	Mean (%)	-50, +44	-66, +147	-78, +223	-21, +23	-34, +36	-49.8, +94.7
Sediment Yield (tonnes)	0	9.9 (0)	21.4 (0)	11.6 (0)	71.2 (0)	228.2 (0)	0.0
	-25	8.2 (-17)	16.5 (-20)	9.30 (-20)	70.3 (-1)	217.2 (-5)	-12.6
	+25	10.5 (6)	25.2 (22)	13.7 (18)	72.5 (2)	236.5 (4)	10.4
	-50	7.9 (-20)	14.8 (-29)	6.0 (-48)	69.0 (-3)	210.2 (-8)	-21.6
	+50	11.0 (11)	26.8 (29)	17.9 (54)	79.6 (12)	243.8 (7)	22.6
	-100	5.8 (-41)	6.7 (-68)	0.0 (-100)	59.3 (-17)	180.2 (-21)	-49.4
	+100	12.6 (27)	34.2 (65)	21.6 (86)	83.7 (18)	275.2 (21)	43.4
	Mean (%)	-26, +15	-39, +39	-56, +53	-7, +11	-11, +11	-27.9, +25.5
Peak Flow (m^3/s)	0	4.5 (0)	2.86 (0)	2.35 (0)	13.48 (0)	34.92 (0)	0.0
	-25	3.15 (-30)	1.59 (-44)	1.38 (-41)	12.27 (-9)	29.71 (-15)	-27.8
	+25	5.43 (21)	4.27 (49)	3.60 (53)	14.00 (4)	39.03 (12)	27.8
	-50	2.74 (-39)	1.05 (-63)	0.46 (-80)	11.77 (-13)	26.18 (-25)	-44.0
	+50	6.05 (34)	5.09 (78)	6.83 (191)	16.56 (23)	42.61 (22)	69.6
	-100	1.38 (-69)	0.09 (-97)	0.00 (-100)	8.22 (-39)	14.74 (-58)	-72.6
	+100	8.32 (85)	10.2 (257)	11.47 (388)	18.60 (38)	59.21 (70)	167.6
	Mean (%)	-46, +47	-68, +128	-74, +211	-20, +22	-33, +36	-48.1, +88.3

yield) for the positive variations (+ 50, 100%). For example, a 100% decrease in API decreased surface runoff, sediment yield, and peak flow by 74.6, 49.4, and 72.6%. In comparison, a 100% increase in API increased surface runoff, sediment yield, and peak flow by 182.6, 43.4, and 167.6%. Mean average variation is most similar for sediment yield (-27.9, +25.5%). This suggests that there is a limit to API and curve number influence on soil erosion.

On an event by event basis, the November 2, 1995 storm experienced the greatest overall variation in surface runoff, sediment yield, and peak flow for both positive and negative percent variations in API (-78, +223%; -56, +53%; -74, +211%; respectively). This event also possessed the highest API of all five storms (20 mm). The next greatest overall changes in output parameter values were observed for events with API's of 15, 14, 8, and 5 mm, respectively. These results would seem to suggest that changes in API have greater influence on events with greater initial antecedent precipitation indices. However, it must be noted that all five events tested have relatively low API's. Events most influenced are those whose antecedent precipitation indices approach mid-range values (20-30 mm). It is also important to note that the events of greatest magnitude (October 21, and November 9, 1996) experienced somewhat similar variations in output parameters though their initial antecedent precipitation indices were dissimilar (5, and 14 mm, respectively).

4.2.2 USLE K, C, and P factor sensitivity

Sensitivity analysis of the K, C, and P factors of the USLE showed the influence of all three factors on output parameters to be virtually identical. The factors' influence on sediment yield is shown in Table 4.5. Sediment yield responses

Table 4.5 Sediment Yield Sensitivity With Respect to USLE Factor Variation

Parameter	Factor Variation (%)	Event					Average Variation (%)
		Oct. 6/95	Oct. 22/95	Nov. 2/95	Oct. 21/96	Nov. 9/96	
		Initial API (mm)					
		8	15	20	5	14	
		Parameter Yield (Percent Change from Zero Variation)					
Sediment Yield (tonnes)	0	9.9 (0)	21.4 (0)	11.6 (0)	71.2 (0)	228.2 (0)	0.0
	-25	8.4 (-15)	17.3 (-19)	9.6 (-17)	63.0 (-11)	184.7 (-19)	-16.2
	+25	11.2 (13)	25.4 (19)	13.5 (16)	80.2 (13)	273.1 (20)	16.2
	-50	6.7 (-32)	12.9 (-40)	7.4 (-36)	55.1 (-23)	144.1 (-37)	-33.6
	+50	12.6 (27)	29.4 (37)	15.4 (33)	90.2 (27)	318.5 (40)	32.8
	-100	1.4 (-86)	1.0 (-95)	0.9 (-92)	44.0 (-38)	85.0 (-63)	-74.8
	+100	15.2 (54)	37.6 (76)	19.3 (66)	112.5 (58)	415.0 (82)	67.2
	Mean (%)	-44, +31	-51, +44	-48, +38	-24, +33	-40, +47	-41.5, +38.7

to USLE factor variation were much consistent than those found for API variation. USLE factor decreases of 25, 50, and 100% resulted in 16.2, 33.6, and 74.8% average decreases in sediment yield, respectively. Increases of the same proportion resulted in mean sediment yield increases of 16.2, 32.8, and 67.2%. No percent level of factor variation resulted in a 100% or greater change in sediment yield. Sediment yield was more greatly influenced by USLE factors than API with mean average variations of -41.5, and +38.7% as opposed to -27.9, and +25.5%.

4.2.3 Sensitivity of the "Hydrograph Shape Factor" toggle parameter

The hydrograph shape factor toggle parameter was observed to have an unusually great influence on AGNPS sediment yield calculation. Model calibration determined that setting this toggle parameter to 56% runoff prior to peak yielded the best simulations. It was also discovered that only the slightest variation in this value can result in an extreme change in sediment yield simulation. Results of this brief sensitivity analysis are presented in Table 4.6.

Percent runoff prior to peak flow was set to 54 and 58% for each event. The 2% increase resulted in sediment yield increases ranging from 9.0 to 40%. A 2% decrease to 54% increased sediment yield from 607 to 1468%! The greatest proportional increases were experienced by the storms of greatest magnitude (October 21, November 9, 1996). The extreme sensitivity of this initial data parameter was unexpected. Accounting for this parameter's sensitivity is beyond the scope of this dissertation, but possible explanations should nevertheless be explored.

Table 4.6 Sediment Yield Sensitivity With Hydrograph Shape Factor Variation

Event	% Runoff Prior to Peak Flow				
	56	54	58	54	58
	Sediment Yield (tonnes)			% Change	
Oct. 6/95	9.9	70.0	13.4	607	35
Oct. 22/95	21.4	165.0	23.3	671	9
Nov. 2/95	11.6	103.9	15.6	796	34
Oct. 21/96	71.2	1116.5	93.0	1468	31
Nov. 9/96	228.2	3410.0	319.8	1394	40

4.3 BMP Evaluation Using AGNPS

As mentioned in previous sections, AGNPS has been shown to be a valuable tool in evaluating BMP effectiveness. The possibility of using AGNPS for this purpose was explored. The one in 10, 25, 50, and 100-year storms of a duration equal to the watershed's time of concentration (approximately 7 hours) were simulated. The storms were assumed to have occurred towards the end of June, when percent crop cover is relatively low and significant soil loss risk is greatest. Simulation results are presented in Table 4.7. Best management practices were evaluated by determining how their adoption would affect sediment yield.

Options for best management practice implementation at the St. Esprit watershed are limited. This limitation is caused by several factors. Firstly, the rectangular shape of fields on the watershed make it impractical for terracing or contouring of land. Strip cropping is also a management option not likely to be adopted. Conservation tillage is an option available, but it can only be used for certain crop covers that are neither harvested too late (vegetables) or prone to leaving residues that leave the soil too moist in the spring (corn residue) and thus inhibit germination.

The most realistic scenario envisioned was one that outlined a four-year conservation crop rotation of soya-corn-corn-grain combined with two-year rotations of grain and corn. Such crop rotations are presently implemented on the basin.

Table 4.7 AGNPS Simulation of 7-hour Storms at Various Recurrence Intervals

Recurrence Interval (years)	Rainfall (mm)	Surface Runoff (mm)	Sediment Yield (tonnes)	Peak Flow (m^3/s)
10	52.86	5.84	56.9	8.44
25	64.49	10.16	92.4	14.37
50	69.78	12.19	110.9	17.3
100	80.35	17.27	231.2	24.05

Conservation tillage leaving a 20-30% soya residue on a future corn field was assumed to reduce the USLE factor C factor by 33% for the first year. The second year of corn in the rotation would not be affected. Conservation tillage with a grain residue was assumed to reduce the C factor by 40% for a future corn crop. Results of simulated BMP implementations on sediment yield reduction for various storms are presented in Table 4.8. Best management practices were assumed to be implemented on the rotations described above for the entire basin, but only for soya and grain fields that could actually leave a residue for following year. The production of a soya or grain crop changing to conservation corn was replaced by a conventional corn crop changing to soya or grain. These assumptions were made to provide a glimpse at the best case scenario for reducing erosion.

Table 4.8 AGNPS BMP Evaluation for a Four-Year Crop Rotation

BMP Implementation Year	**Storm Recurrence Interval (Years)**				
	10	**25**	**50**	**100**	**Average**
	Sediment Yield (tonnes) (% Reduction In Erosion)				
0 (soya or grain)	56.9	92.4	110.9	231.2	122.9
1 (cons. corn)	45.4 (20.2)	72.9 (21.1)	87.7 (20.9)	172.8 (25.2)	94.7 (21.9)
2 (conv. corn or grain)	49.6 (12.8)	79.9 (13.5)	96.2 (13.2)	192.9 (16.6)	104.7 (14.0)
3 (grain or cons. corn)	42.7 (25.0)	67.7 (26.7)	81.1 (26.9)	157.2 (32.0)	87.2 (27.7)
4 (soya or grain)	47.0 (17.4)	75.5 (18.3)	90.9 (18.0)	180.7 (21.8)	98.5 (15.1)
Mean (years 1-4)	46.2 (18.9)	74.0 (19.9)	89.0 (19.8)	175.9 (23.9)	96.3 (19.7)

With such crop rotations under conservation tillage, AGNPS simulated average soil loss reductions of 21.9% during the first year of BMP implementation (second crop rotation year) for the high magnitude storms of Table 4.7. Soil loss reductions would then decrease in the second year due to the replacement of corn under conservation tillage by corn or grain under conventional tillage. This is represented by the 14.0% average soil reduction as compared to year zero, before BMP implementation. The greatest benefits are produced in the final crop rotation year (third year of BMP implementation) with average sediment yield reductions of 27.7% for all four event types. This benefit is due to the replacement of corn under conventional tillage by grain, and the replacement of grain by corn under conservation tillage. The fourth year of BMP implementation returns to the first crop rotation year where lesser average soil loss reductions of 15.1% are observed. When considering the storms separately, and over the 4 crop rotation years, greatest savings in soil erosion were calculated at 23.9% for the 1-in-100-year event. The three other storms resulted in average soil loss reductions of approximately 19 to 20%.

Due to the many optimistic assumptions made in choosing this particular BMP implementation scenario, the soil loss reductions calculated by AGNPS are, in all probability, unrealistically high. However, reducing the estimated reductions from 15-25% to 10-15, or 10-20%, nevertheless represents noteworthy soil conservation gains when considering the very minimal management practices implemented. This analysis would also suggest that AGNPS can effectively evaluate best management practices for the St. Esprit watershed.

5.0 SUMMARY AND CONCLUSIONS

5.1 Summary

The hydrology and water quality of a small rural watershed in Quebec was studied from April 1994 to December 1996. The AGNPS hydrologic/water quality model was used to predict surface runoff, sediment yield, and peak flow at the watershed outlet. Observed hydrologic data were obtained from water level and precipitation readings recorded by automated gauging station instrumentation. Water quality data were determined at the watershed outlet through an intensive event-based sampling program.

AGNPS input parameters were determined through available maps, literature, and aerial photography. Seven rainfall-runoff events were used to calibrate the model. Initial AGNPS simulations were performed using the SCS Curve Number method AMC criteria as soil moisture indicators. The antecedent precipitation index was used as a soil moisture indicator, and was correlated to the SCS curve number. Five events were used in model validation. Observed and simulated output parameters for all twelve events were compared in order to determine AGNPS' predictive abilities. A sensitivity analysis of input parameters and a best management practice evaluation were run using AGNPS.

5.2 Conclusions

Initial AGNPS simulation results produced average errors of 47.1, 129.9, and 43.4% for surface runoff, sediment yield, and peak flow, respectively. Corresponding coefficients of performace were 2.66, 0.74, and 3.73, respectively. Final model calibration demonstrated considerable improvements. Average errors of 6.2, 38.9, and 44.3% were observed for surface runoff, sediment yield, and peak flow, respectively. Corresponding CP'_A's decreased to 0.05, 0.43, and 0.12, respectively. Validation results produced average errors of 21.7, and 13.2% for surface runoff, and sediment yield, respectively. Model validation for these parameters produced low CP'_A's of 0.02, and 0.01, respectively. Average peak flow simulation did not improve and yielded an average error and CP'_A of 117.8%, and 2.07, respectively.

The use of API as a soil moisture indicator, when correlated to curve number, was observed to improve model simulation. This method demonstrated AGNPS to be a valid tool for watershed modeling on the St. Esprit basin when surface runoff and sediment yield were considered. However, AGNPS was observed to generally overpredict peak flow. AGNPS performed best when events occurring between June 1 and November 1 were simulated. Poorer model performance was observed when complex storms and events occurring during periods of relatively cold climatic conditions (early spring and fall events) were simulated.

API and related curve number were observed to be the most sensitive input parameters, influencing surface runoff, sediment yield, and peak flow to considerable degrees. Sediment yield prediction was most sensitive to USLE factor variation. The hydrograph shape factor initial data input parameter demonstrated extreme and unforeseen sensitivity.

Best case scenario BMP evaluation using AGNPS demonstrated average soil loss reductions ranging between 15 and 25% when 1-in-10, 25, 50, and 100 year storms were simulated.

This dissertation demonstrates the applicability of the AGNPS model to soil and hydrologic conditions in Quebec, and will prove useful in testing and refining hydrologic/water quality models in this province. This study ultimately represents a further contribution to the development of NPS pollution control strategies applicable to agricultural regions in Quebec.

6.0 RECOMMENDATIONS FOR FUTURE RESEARCH

1. Over a three-year period, there was a limited amount of runoff data that could be used in AGNPS model calibration and validation. Continued monitoring of the St. Esprit watershed would provide a greater amount of observed events available for simulation. This, in turn, would improve the model's performance.

2. When calibrated API and associated curve numbers were used, AGNPS was generally unable to adequately simulate events occurring in April, May, and mid to late November. It seems likely that seasonal adjustments to API and curve number would have to be made in order to satisfactorily model these events. Use of the forthcoming, continuous version of AGNPS (AGNPS 6.0) may also aid in achieving this goal.

3. AGNPS must be tested on other watersheds in Quebec in order to establish its applicability to soil and climatic conditions in this province. The model's main shortfall, its use of the SCS Curve Number method, (which has been shown to be inappropriate for Quebec conditions) has been circumvented in this investigation through the use of API. Similar correlations between API and curve number can be developed for other basins in order to use AGNPS more effectively.

4. A more detailed sensitivity analysis needs to be conducted in order to account for the extreme influence of the hydrograph shape factor parameter.

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APPENDIX 1

SCS Curve Numbers and USLE C Factors

Used in Final

AGNPS Model Calibration

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Fig. A1.1 CN vs. API: Residential/Soil Type A

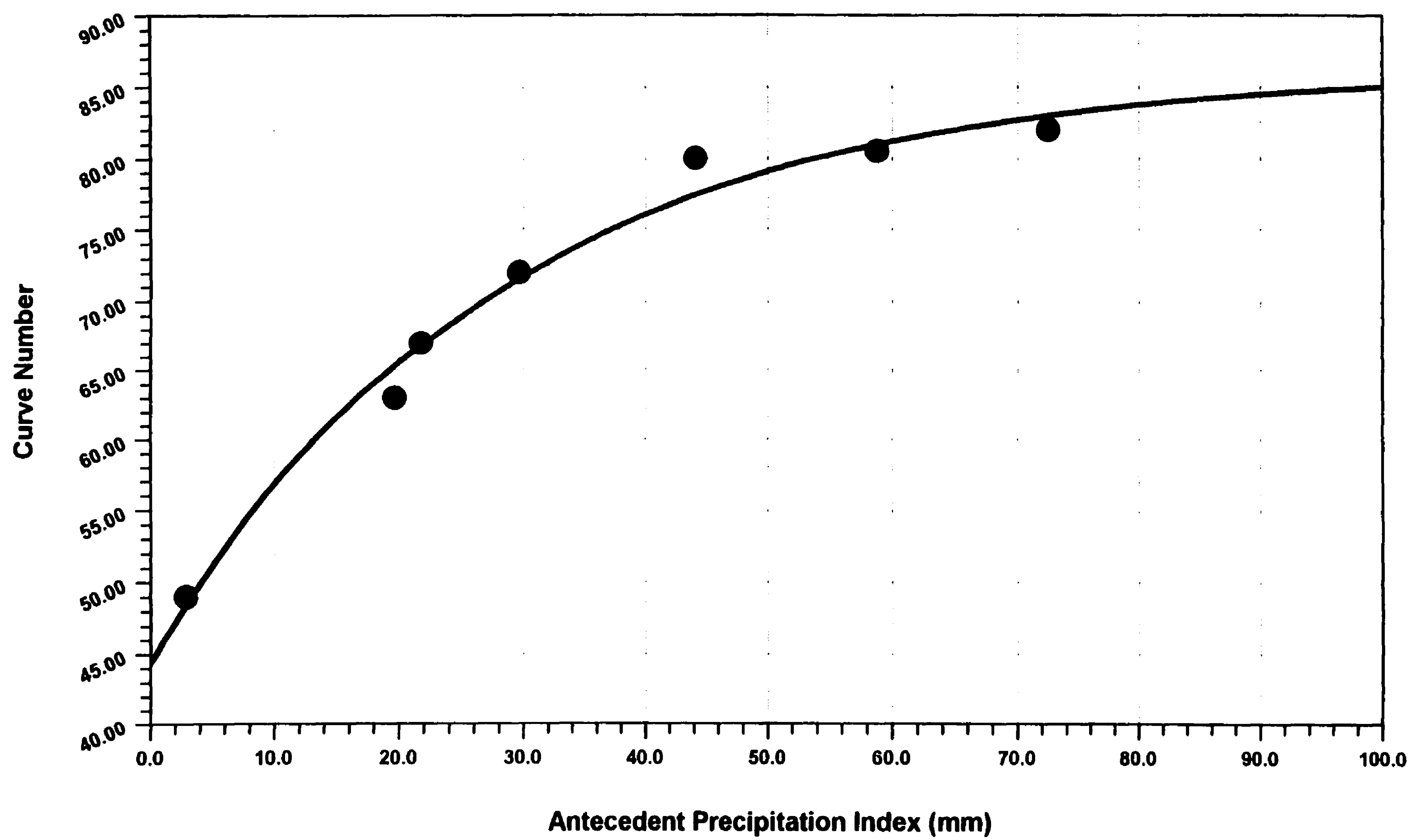

Fig. A1.2 CN vs. API: Grain/Soil Type A

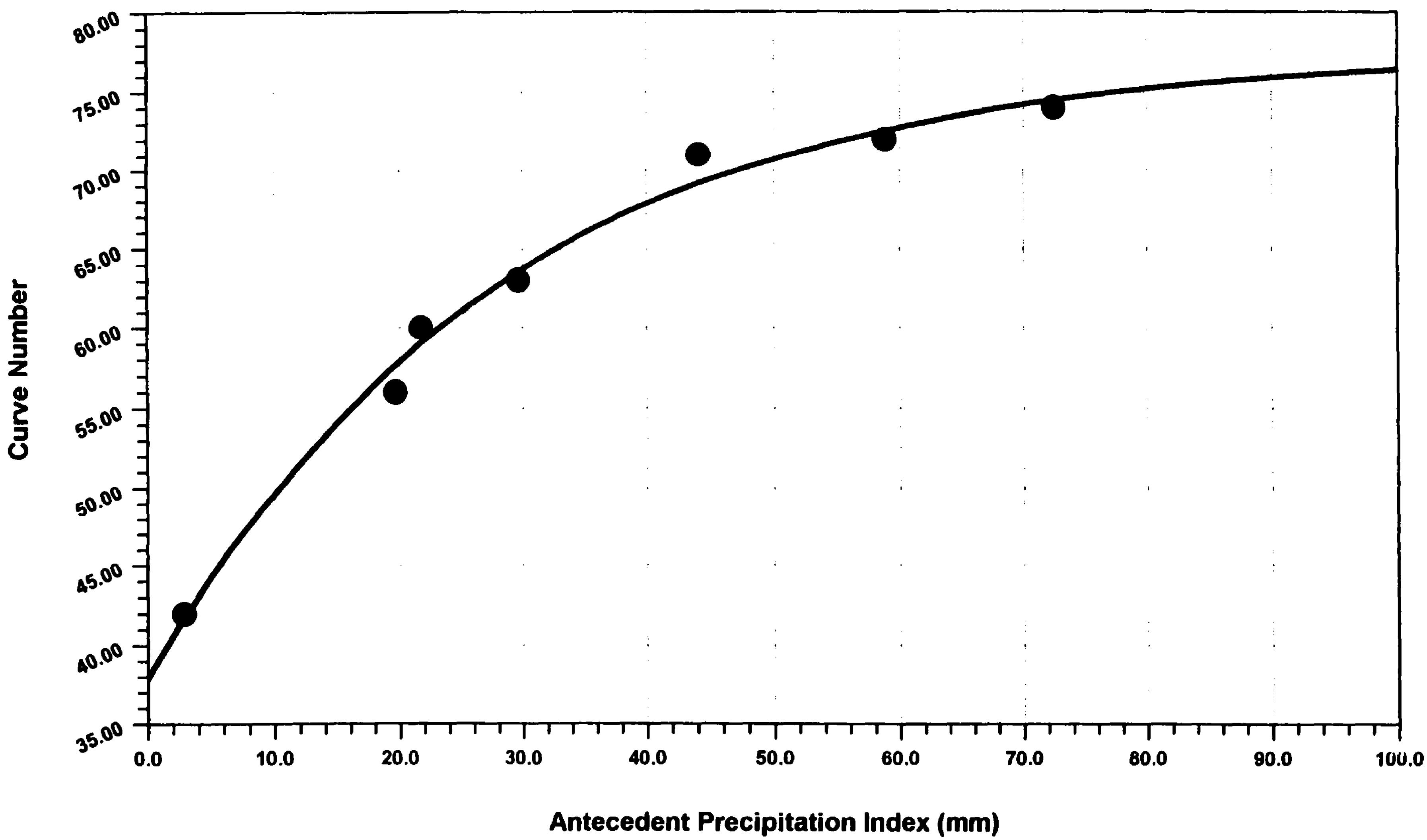

Fig. A1.3 CN vs. API: Pasture/Soil Type A

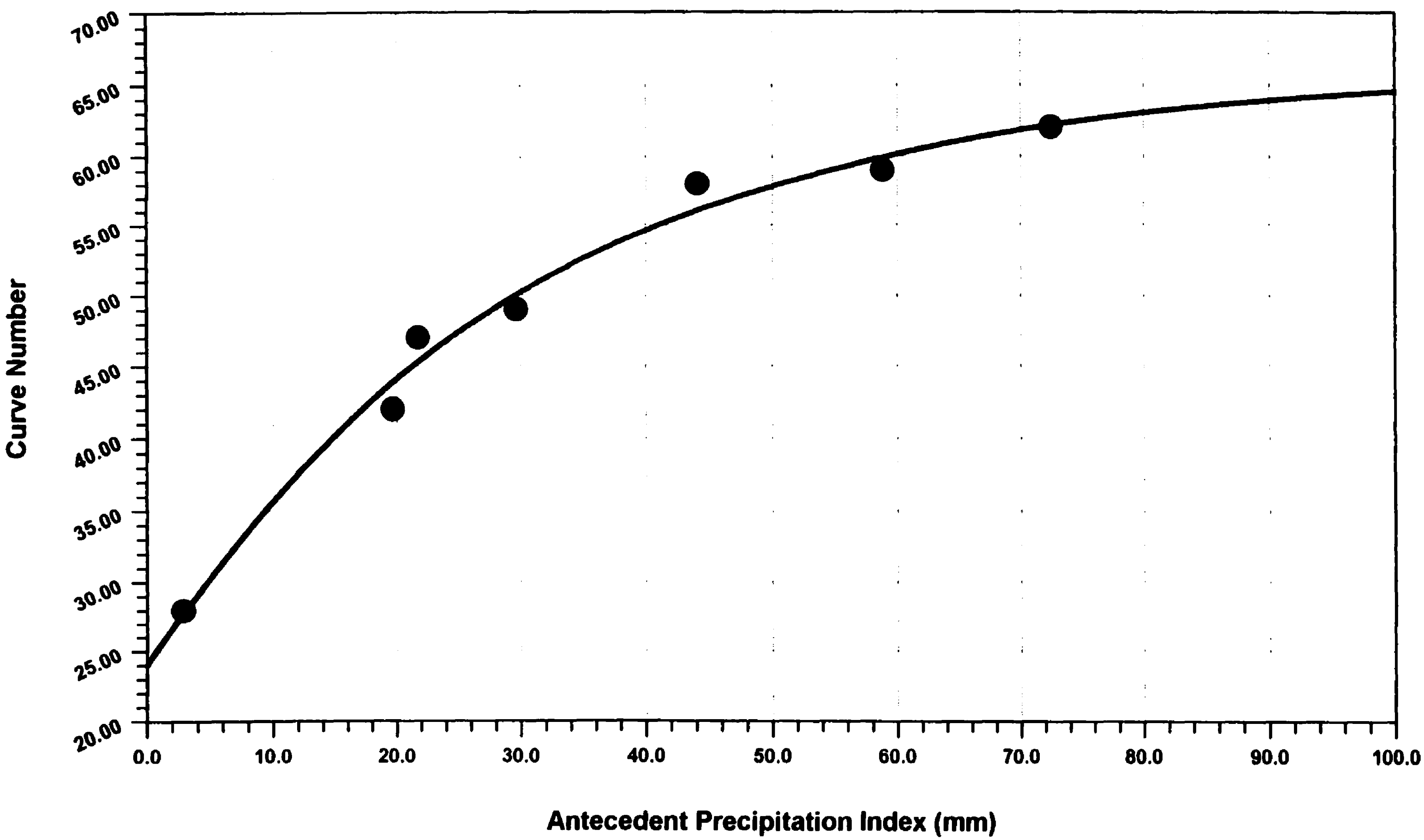

Fig. A1.4 CN vs. API: Row Crops/Soil Type A

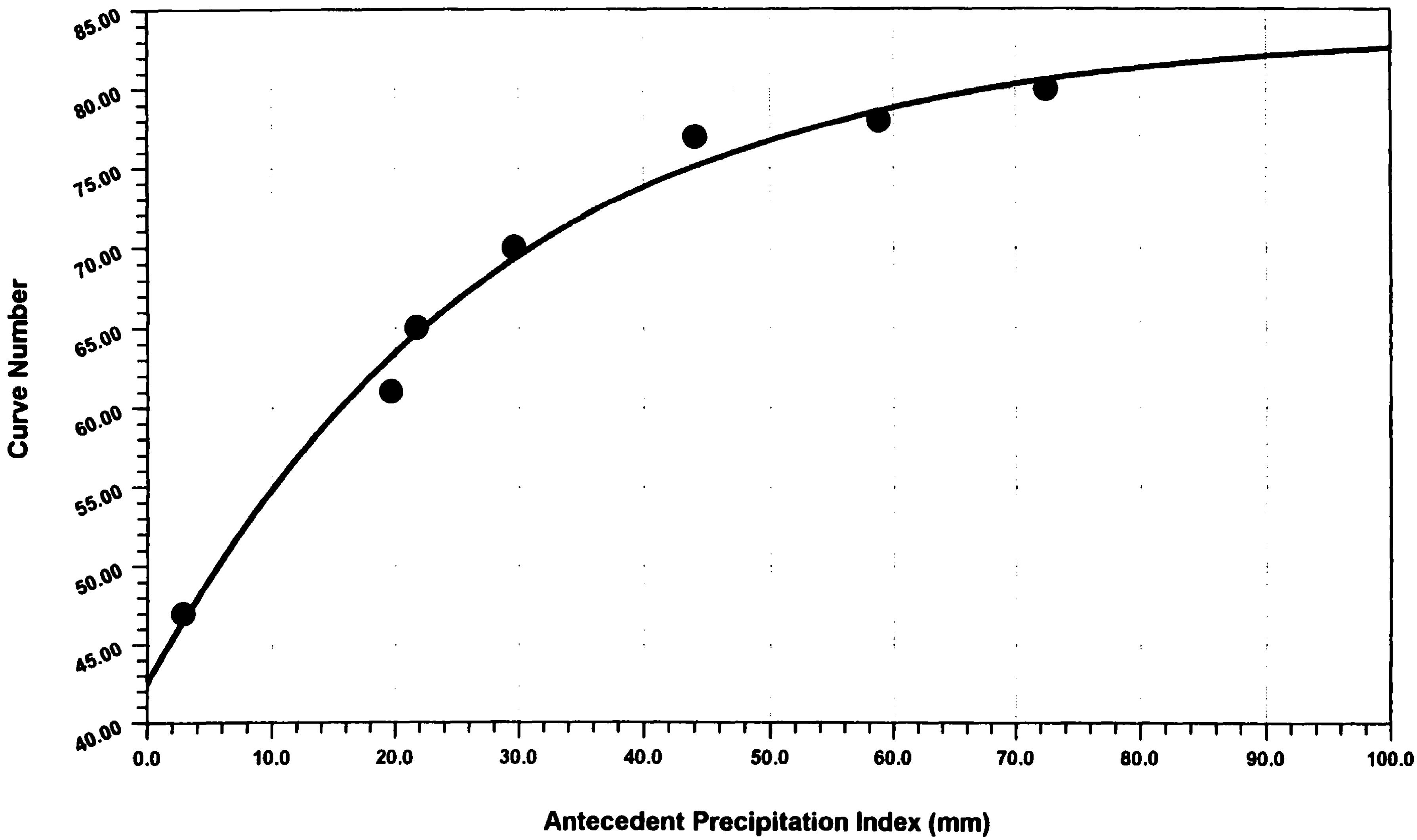

Fig. A1.5 CN vs. API: Forest/Soil Type A

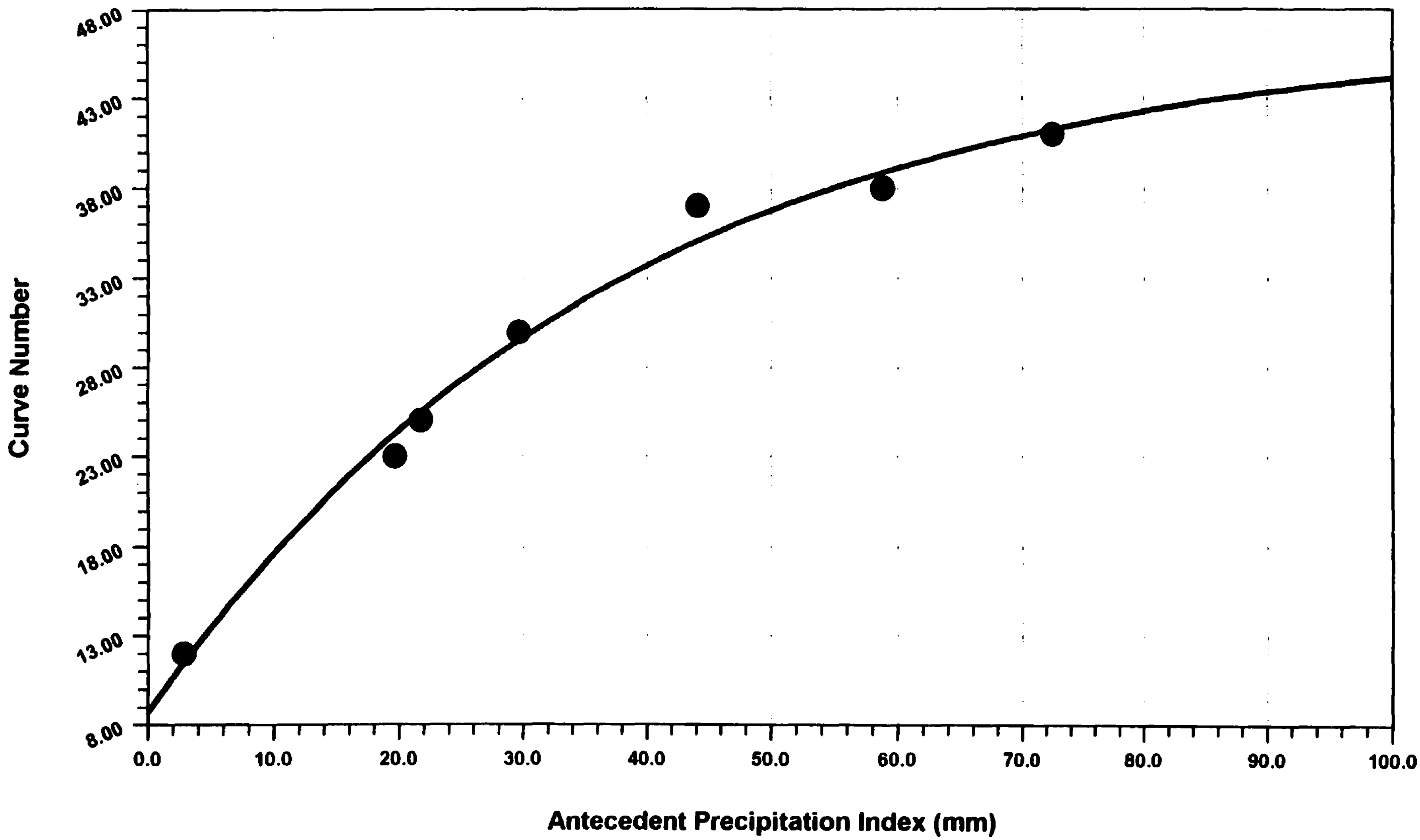

Fig. A1.6 CN vs. API: Residential/Soil Type B

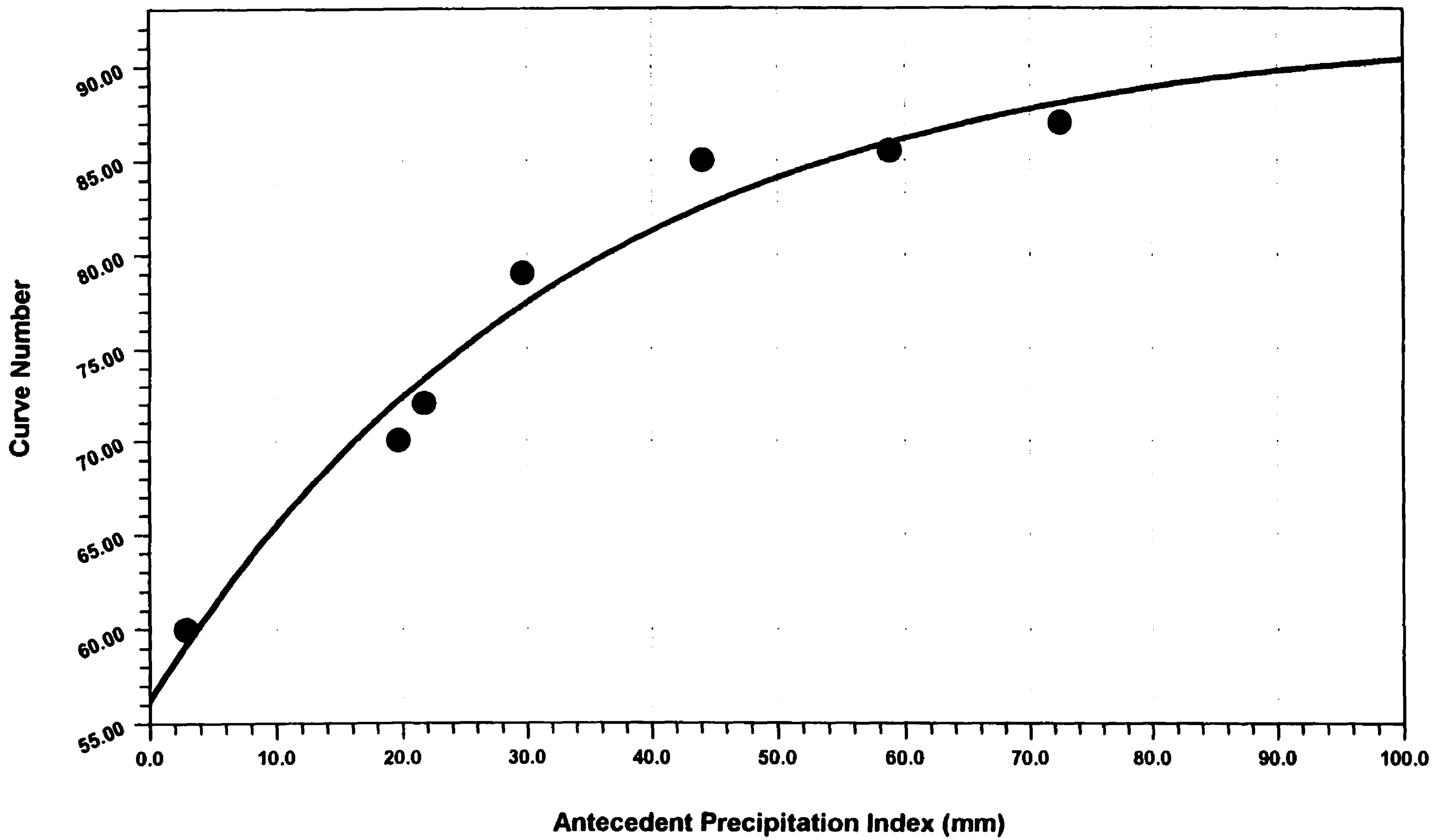

Fig. A1.7 CN vs. API: Grain/Soil Type B

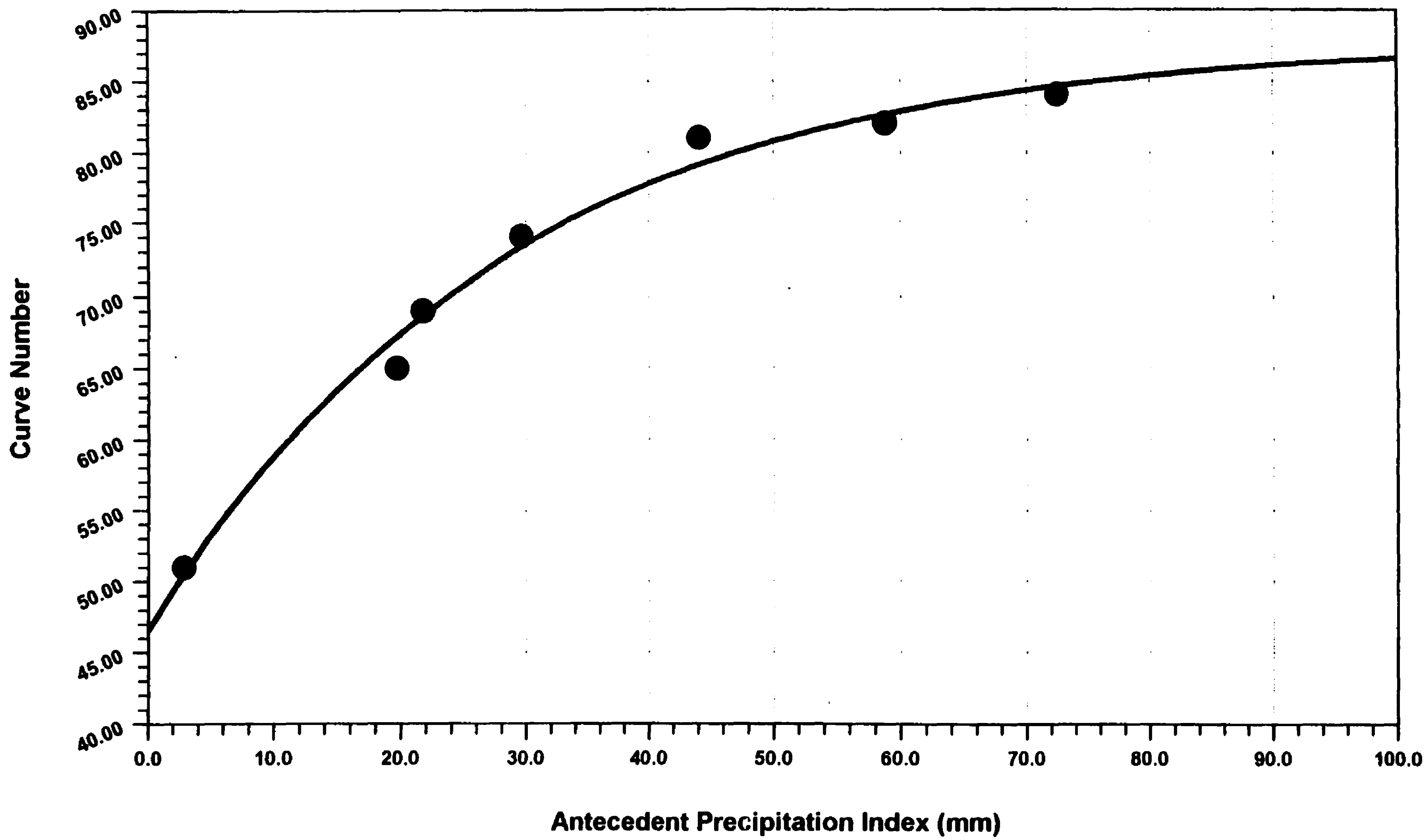

Fig. A1.8 CN vs. API: Pasture/Soil Type B

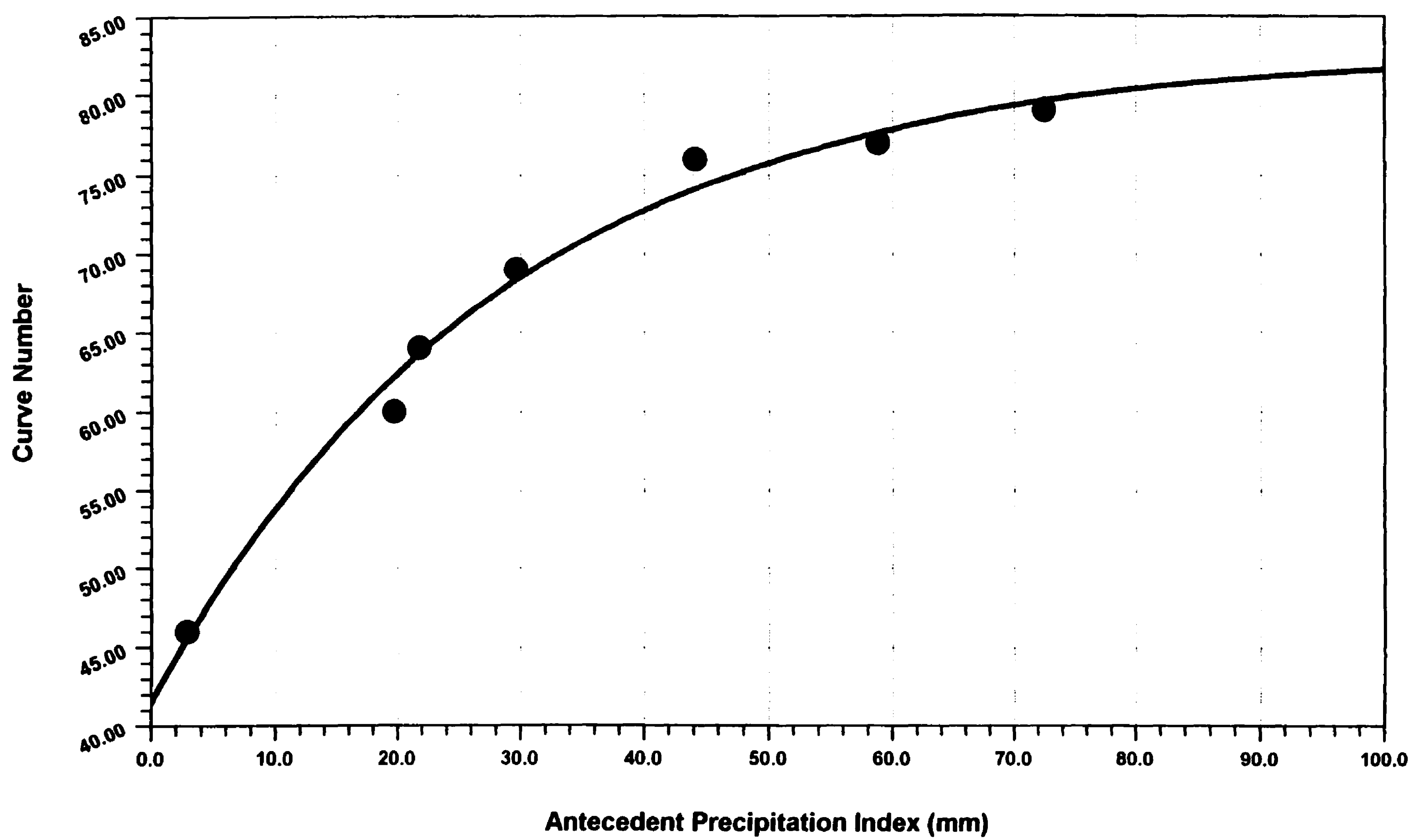

Fig. A1.9 CN vs. API: Row Crops/Soil Type B

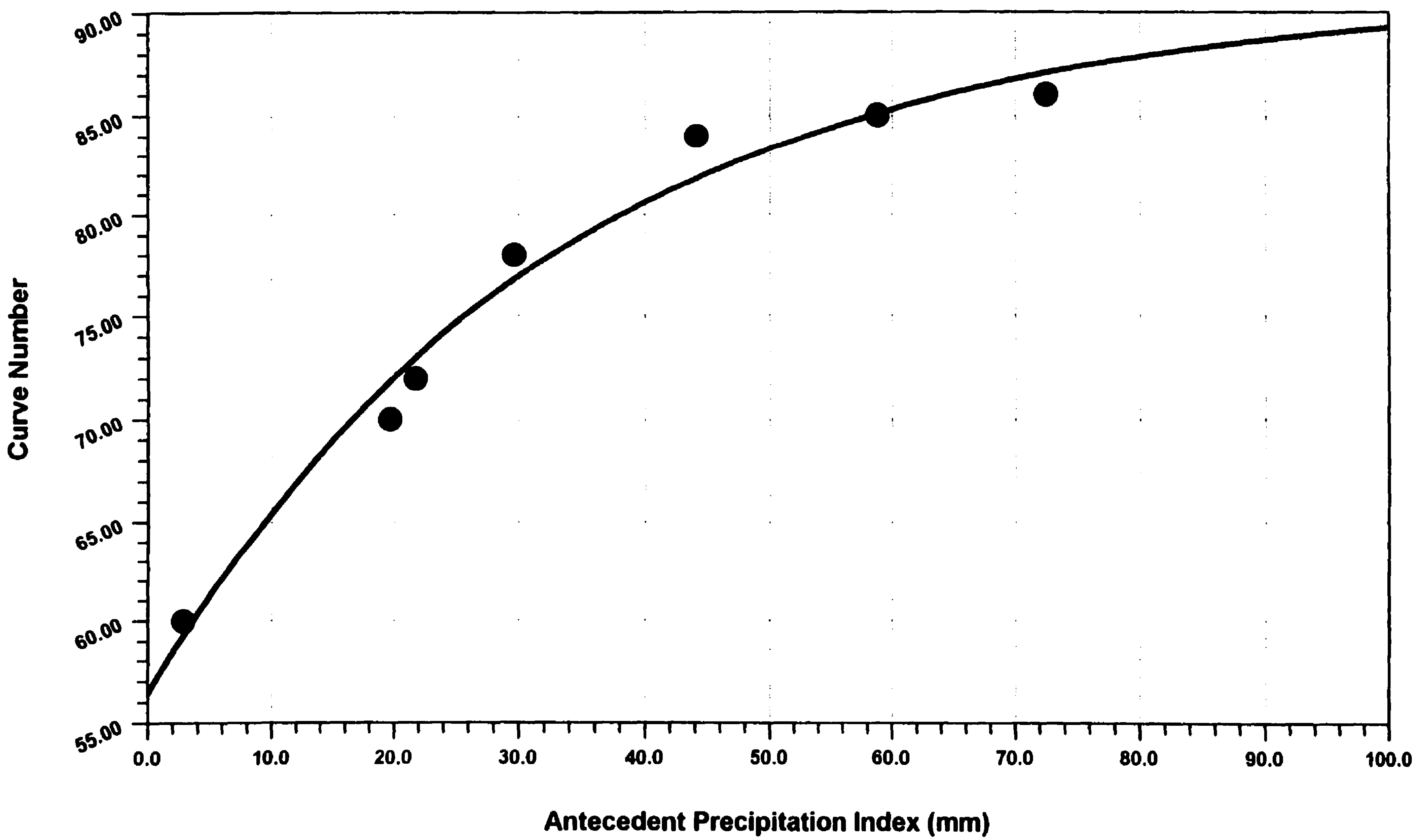

Fig. A1.10 CN vs. API: Forest/Soil Type B

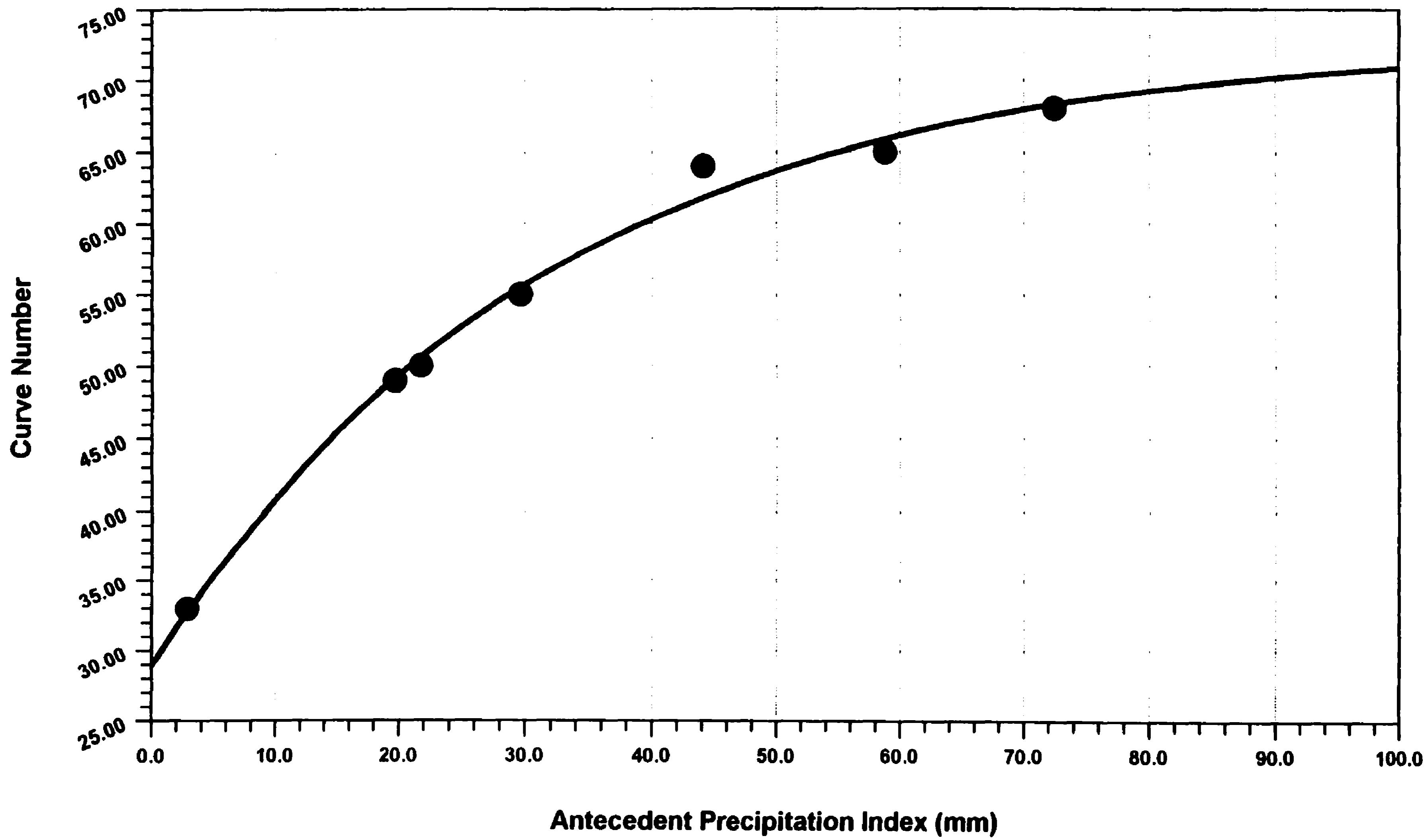

Fig. A1.11 CN vs. API: Residential/Soil Type C

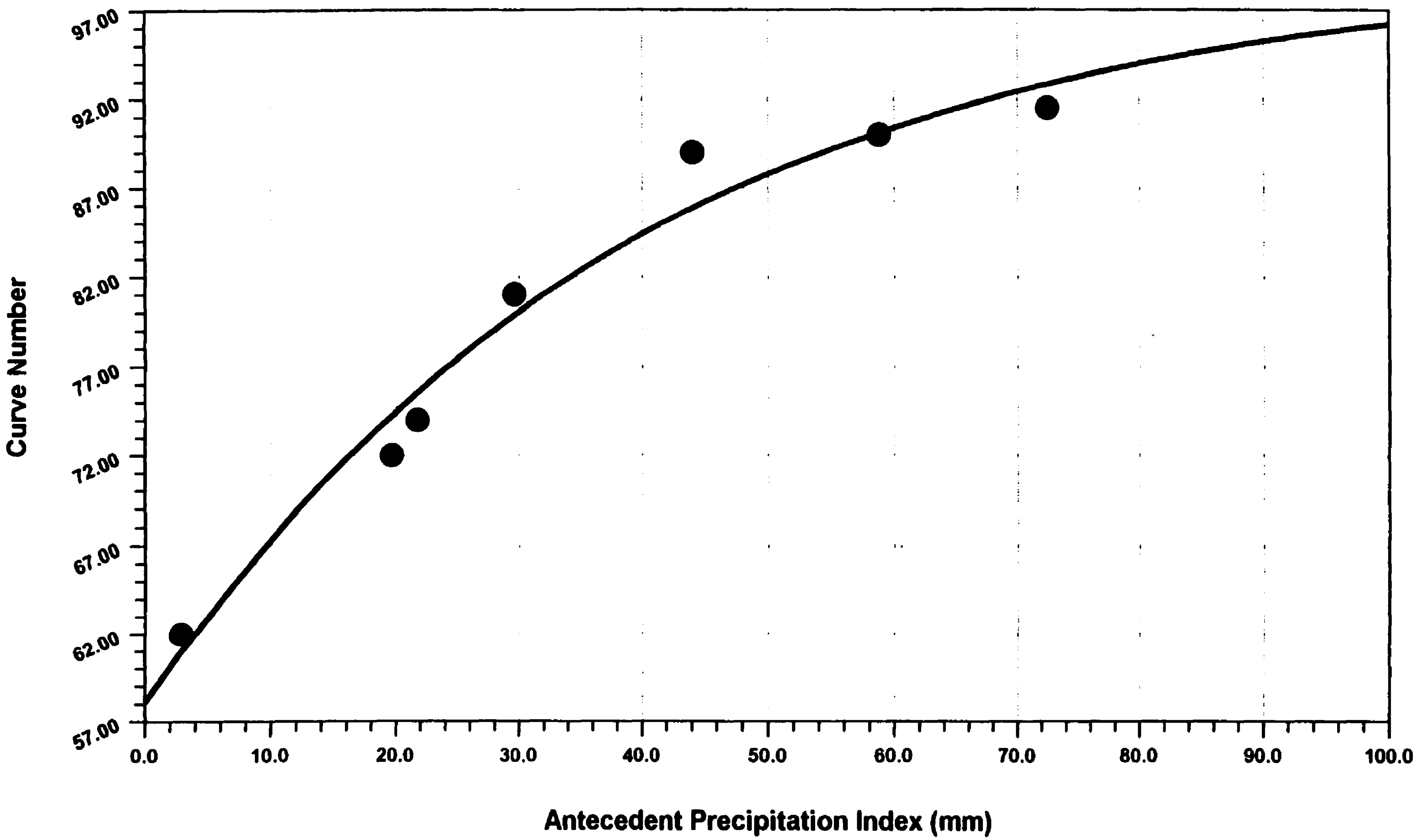

Fig. A1.12 CN vs. API: Grain/Soil Type C

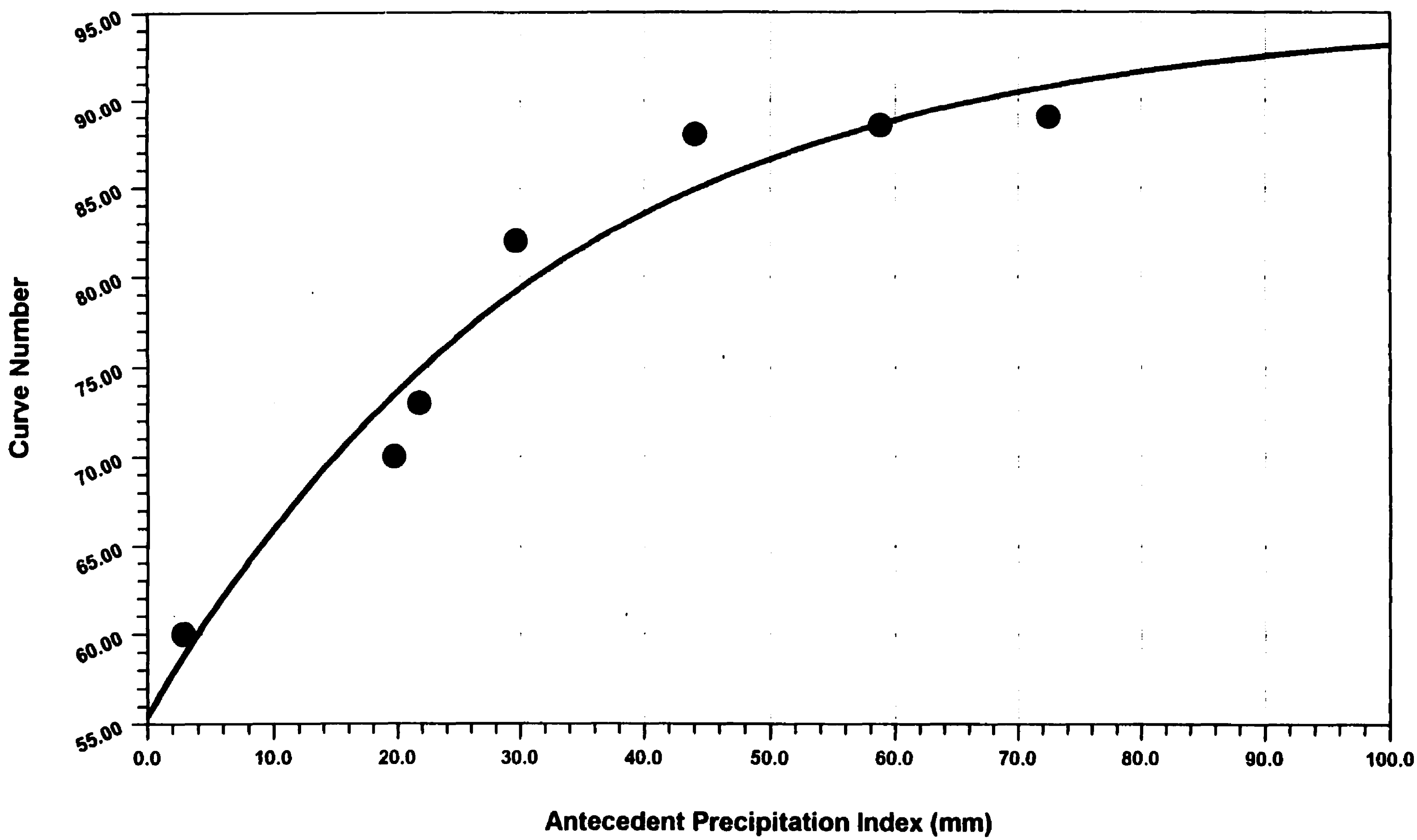

Fig. A1.13 CN vs. API: Pasture/Soil Type C

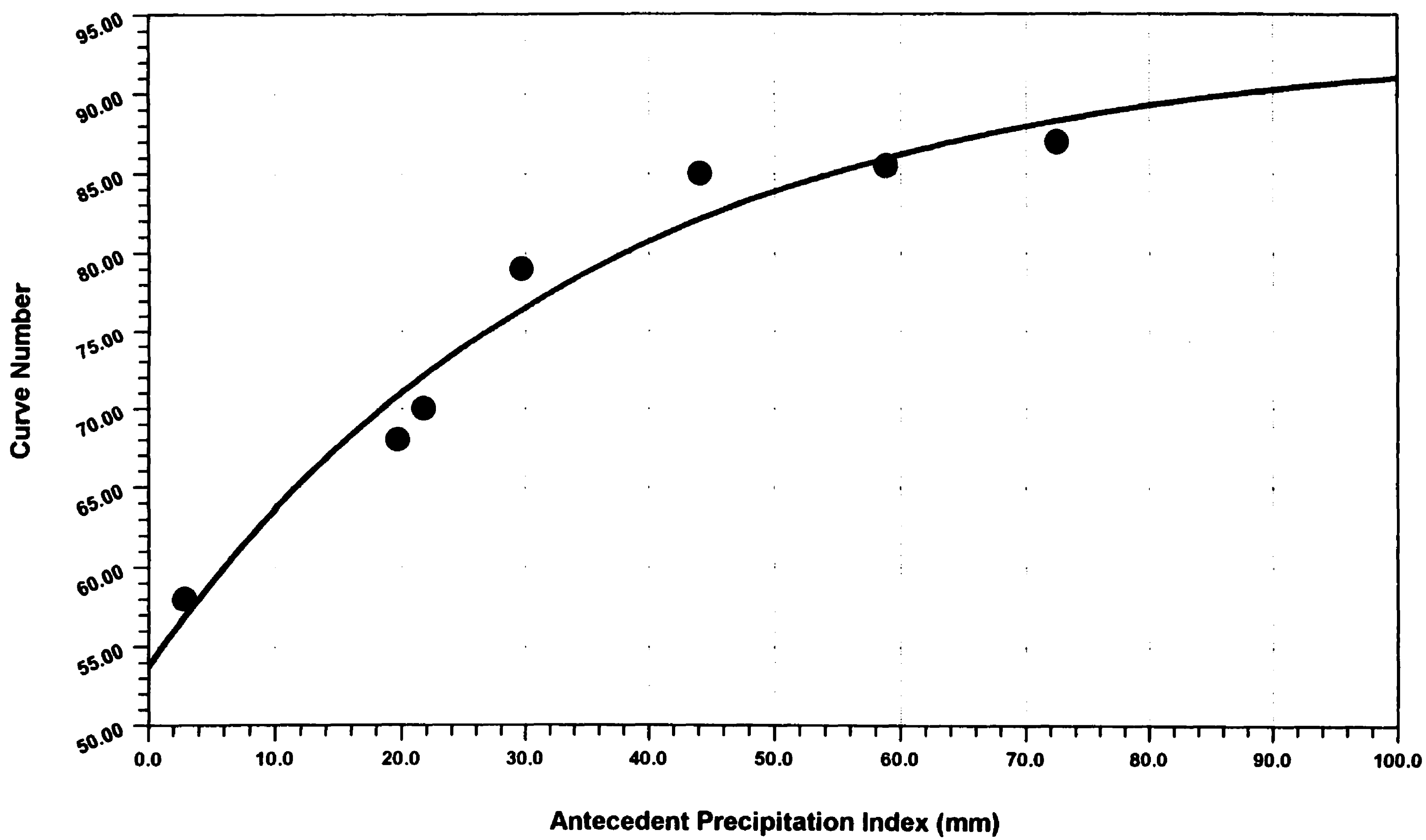

Fig. A1.14 CN vs. API: Row Crops/Soil Type C

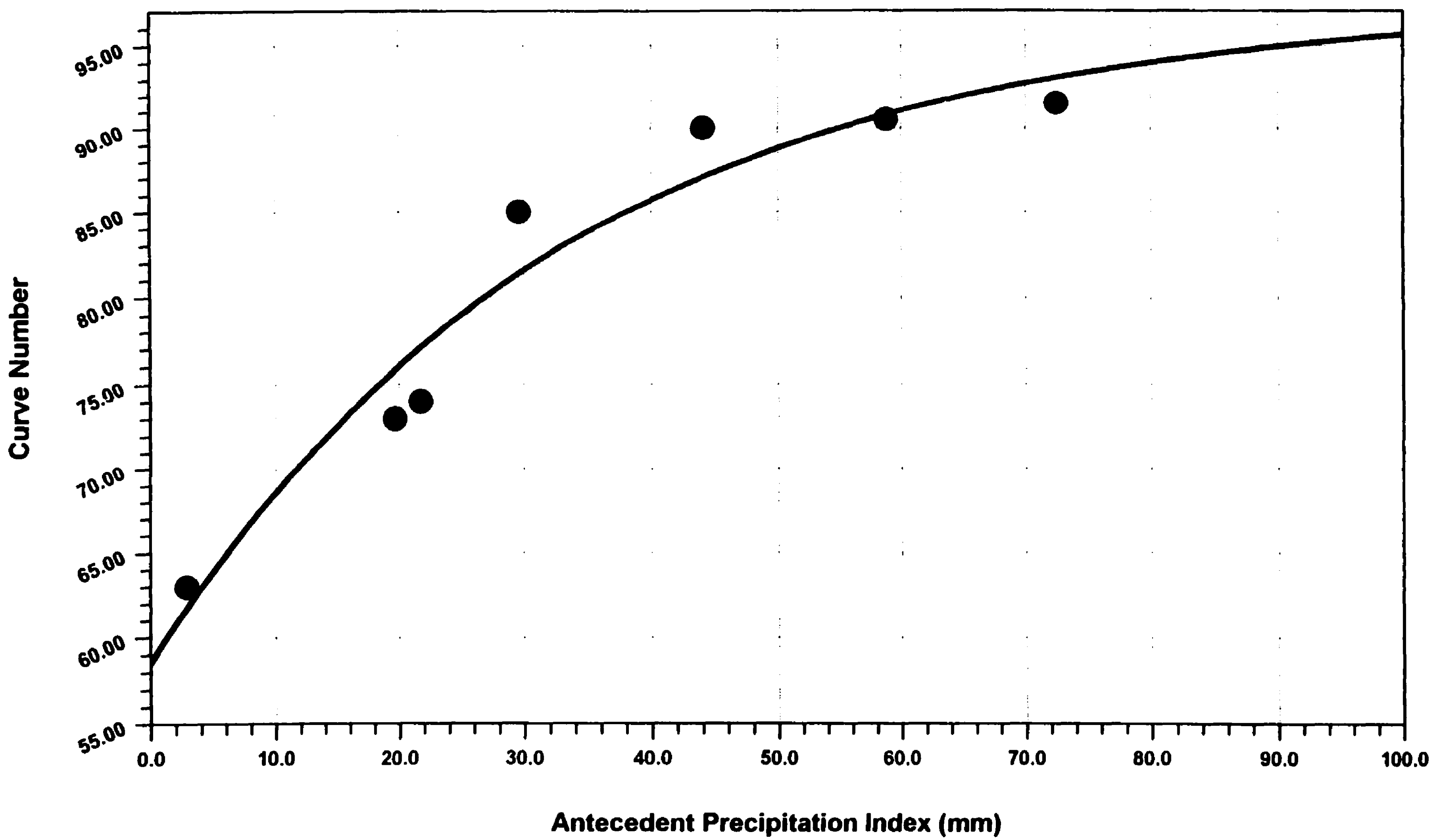

Fig. A1.15 CN vs. API: Forest/Soil Type C

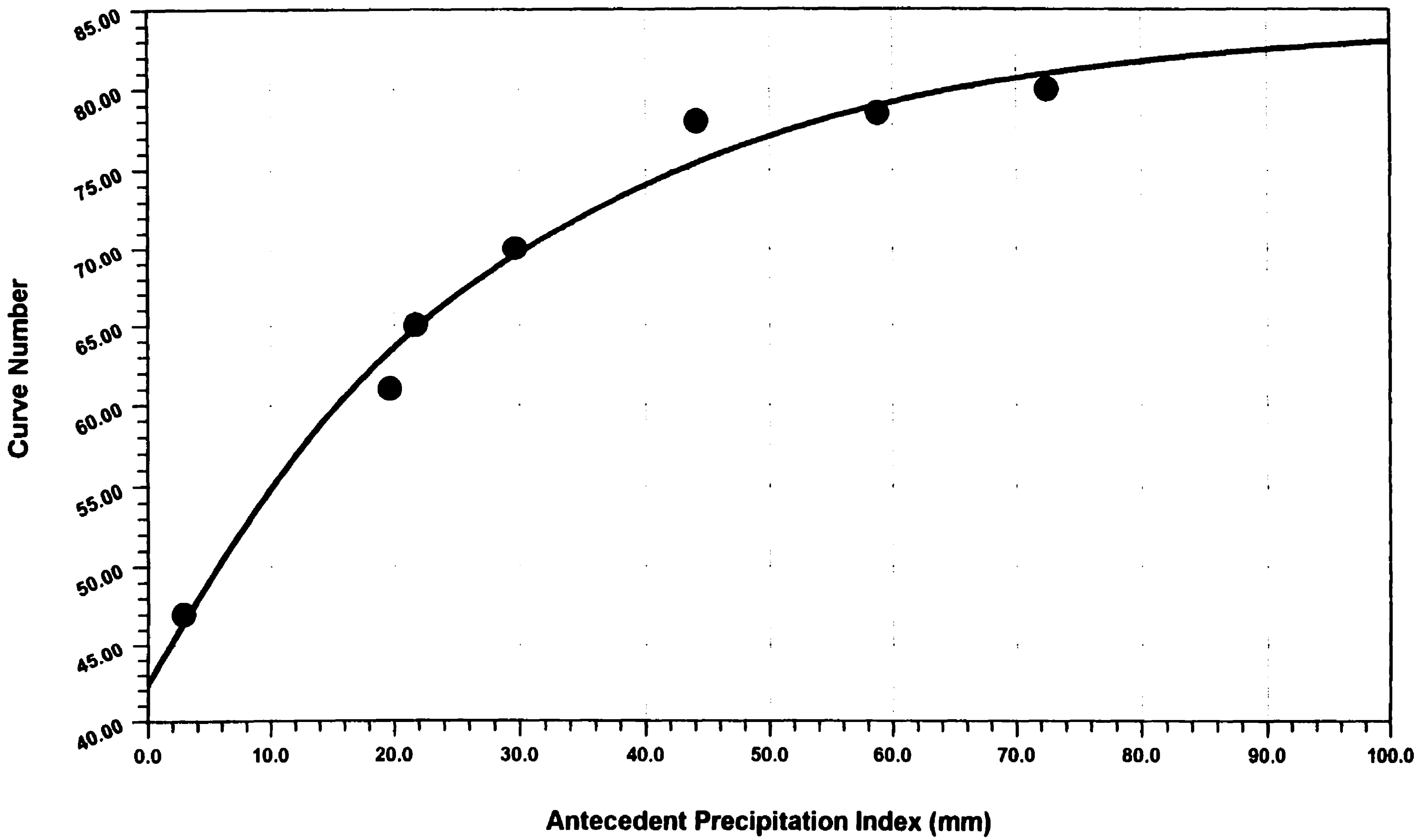

Fig. A1.16 CN vs. API: Residential/Soil Type D

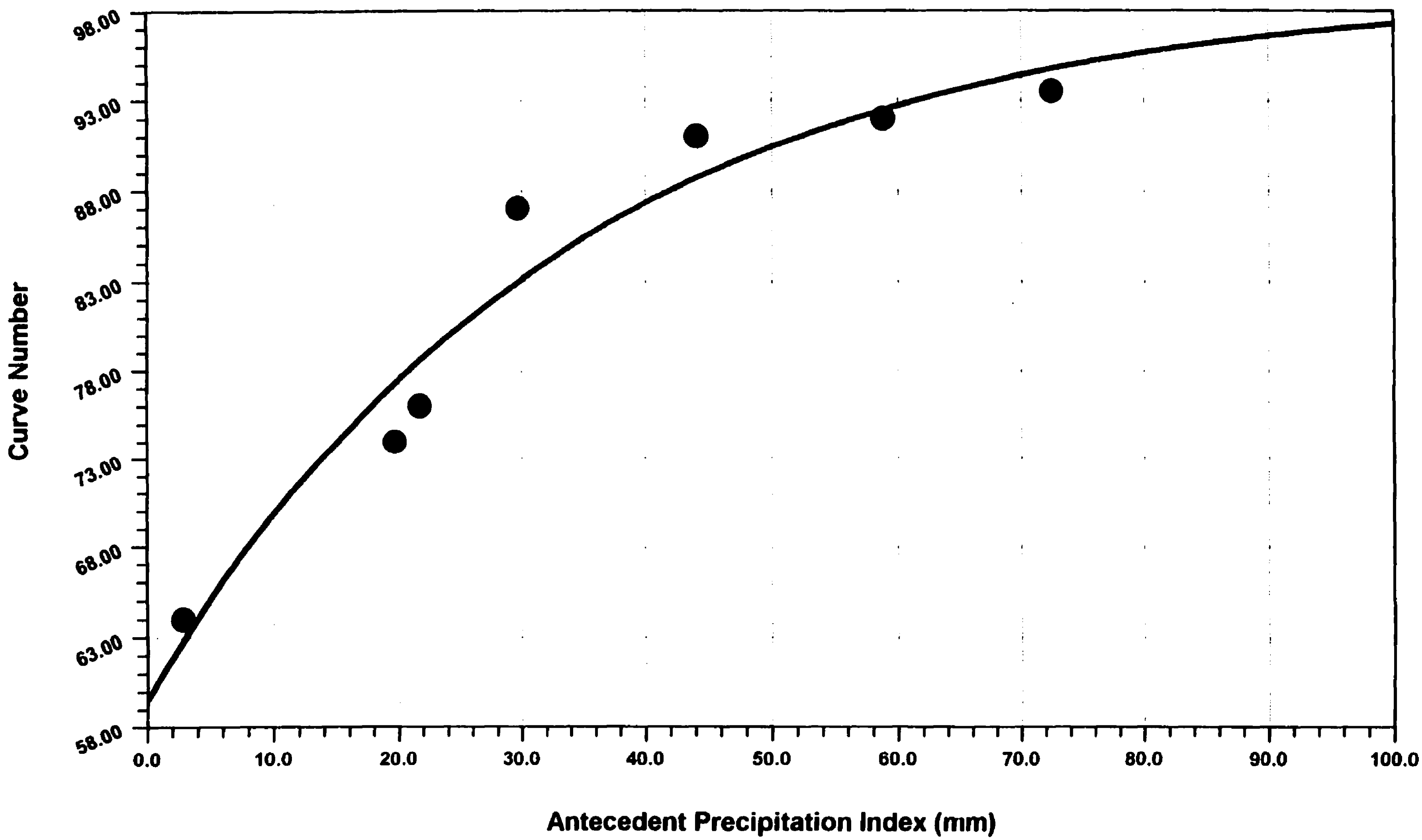

Fig. A1.17 CN vs. API: Grain/Soil Type D

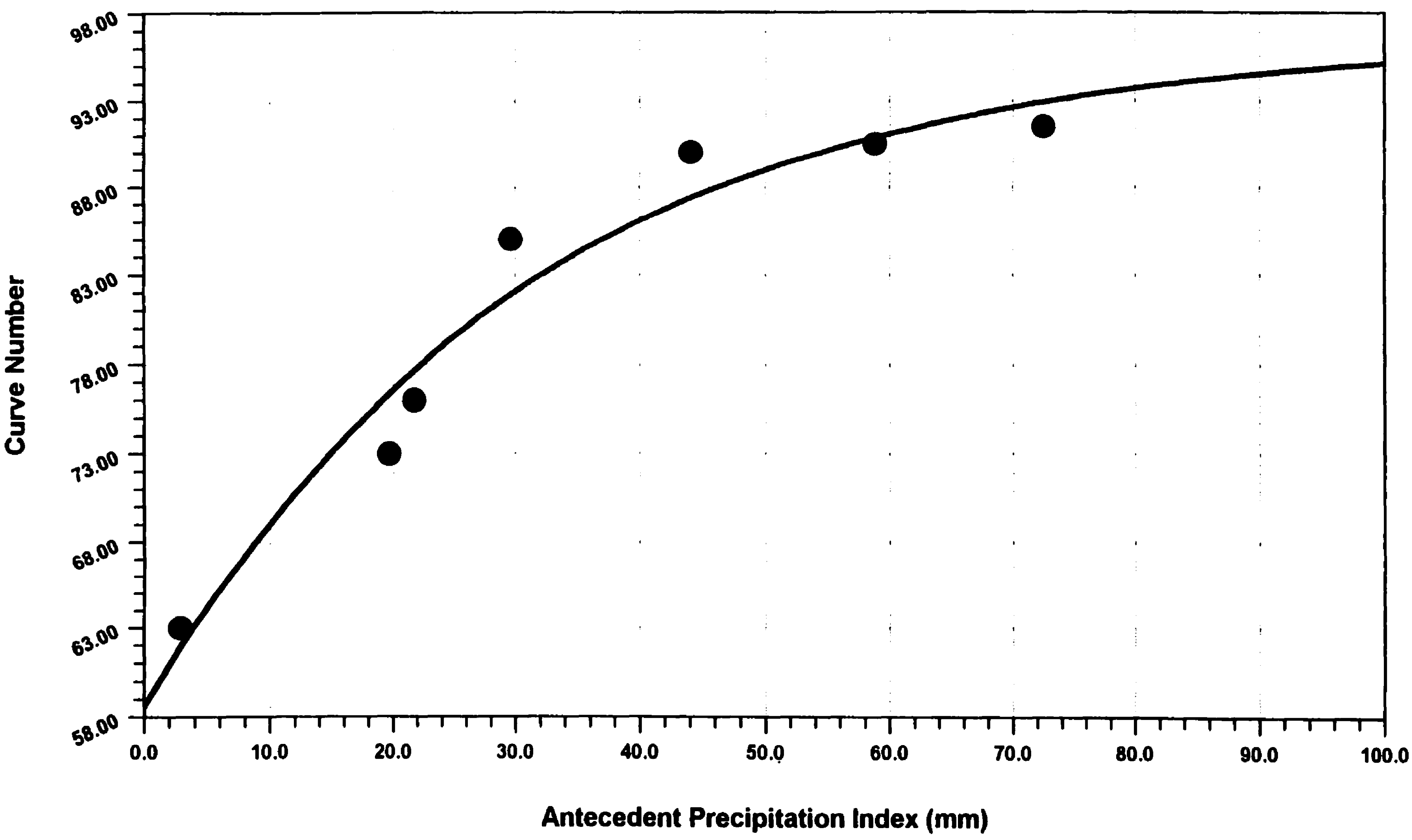

Fig. A1.18 CN vs. API: Pasture/Soil Type D

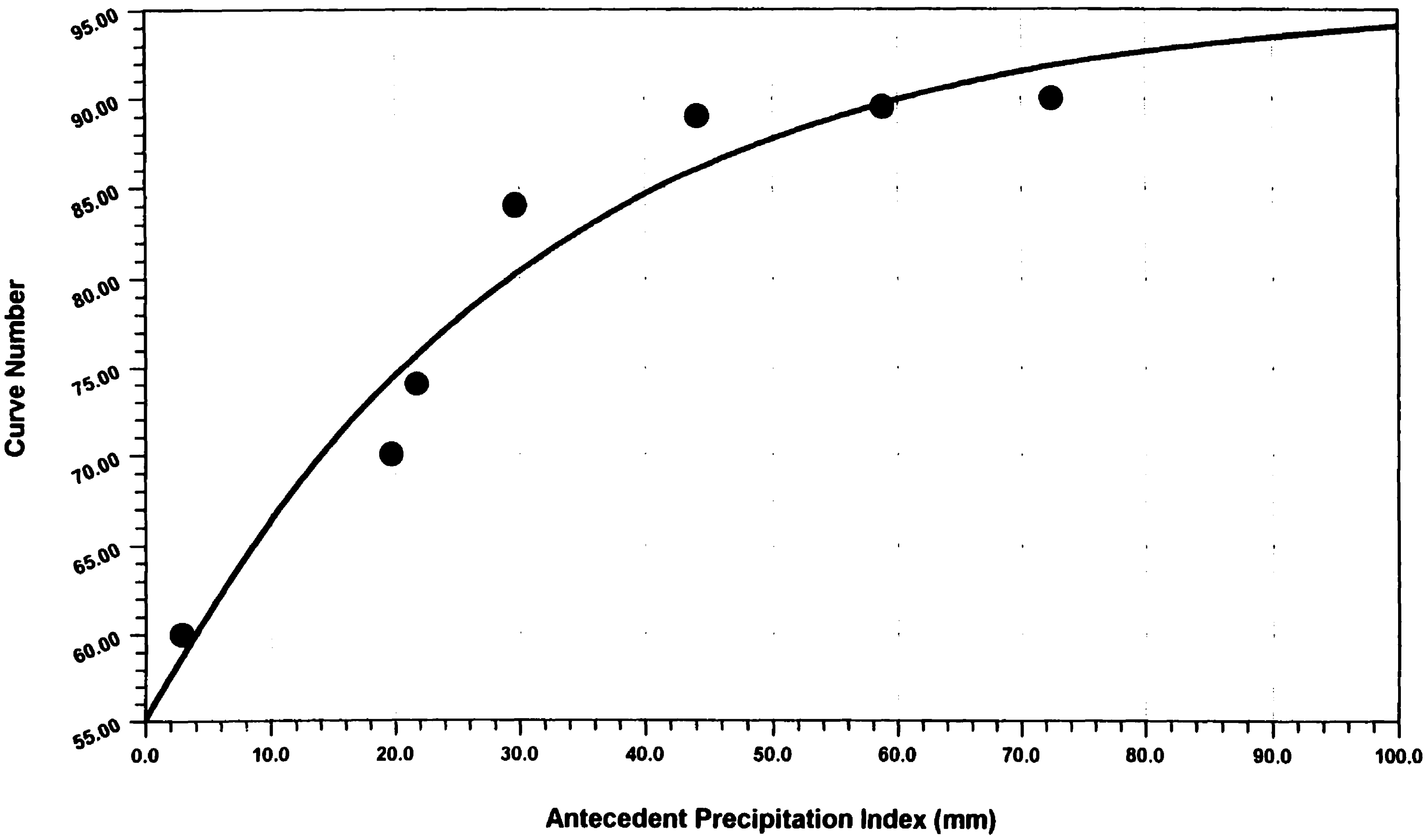

Fig. A1.19 CN vs. API: Row Crops/Soil Type D

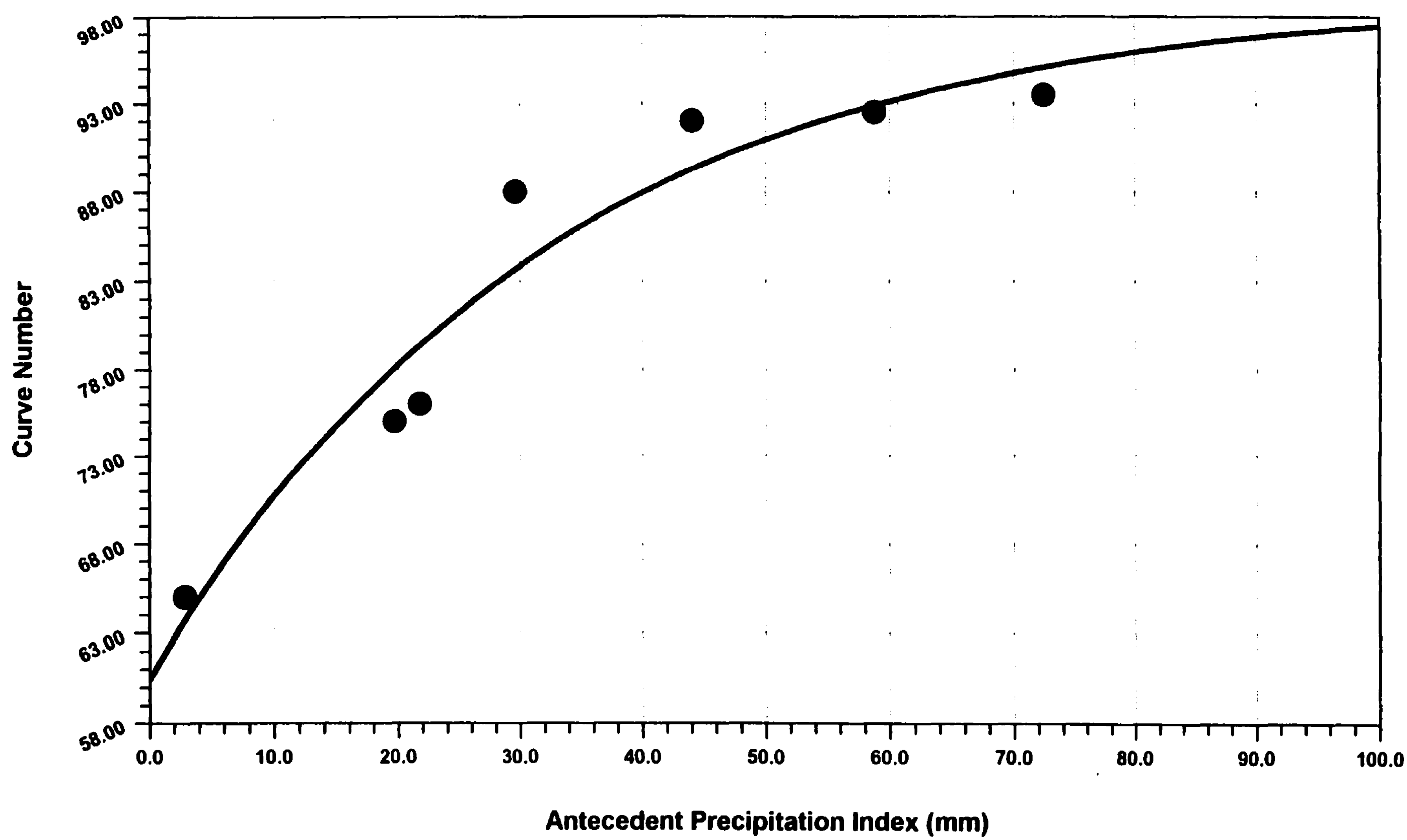

Fig. A1.20 CN vs. API: Forest/Soil Type D

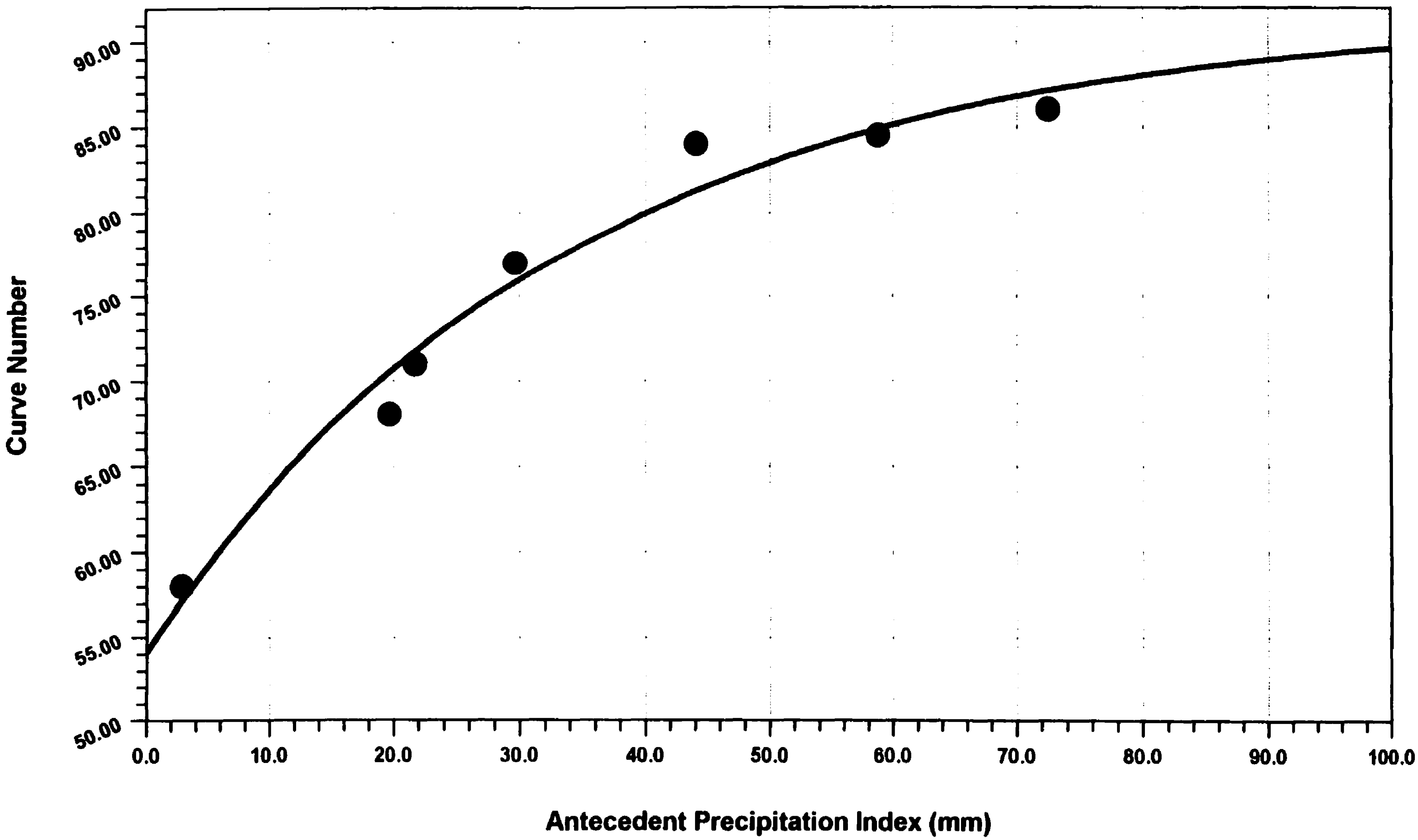

Table A1.1 Runoff Curve Numbers Used in AGNPS Model Calibration

Soil Group	Cover Condition	Event						
		June 13	June 25	June 27	June 29	Aug. 2	Aug. 5	Nov. 1
		Curve Number						
A	**Residential**	72	63	80.5	82	67	80	49
	Row Crop	70	61	77.5	80	65	77	47
	Grain	63	56	72	74	60	71	42
	Pasture	49	42	59	62	47	58	28
	Forest	30	23	38	41	25	37	12
B	**Residential**	79	70	85.5	87	72	85	60
	Row Crop	78	70	85	86	72	84	60
	Grain	74	65	82	84	69	81	51
	Pasture	69	60	77	79	64	76	46
	Forest	55	49	65	68	50	64	33
C	**Residential**	81	72	90	91.5	74	89	62
	Row Crop	85	73	90.5	91.5	74	90	63
	Grain	82	70	88.5	89	73	88	60
	Pasture	79	68	85.5	87	70	85	58
	Forest	70	61	78.5	80	78	65	47
D	**Residential**	87	74	92	93.5	76	91	64
	Row Crop	88	75	92.5	93.5	76	92	65
	Grain	85	73	90.5	91.5	76	90	63
	Pasture	84	70	89.5	90	74	89	60
	Forest	77	68	84.5	86	71	84	58

Table A1.2 USLE C Factors Used in AGNPS Model Calibration

Time Period	USLE C Factors for Given Land Use							
	Residential	Corn	Vegetables	Soya	Grain	Hay	Pasture	Forest
June 1-15	0.01	0.36	0.12	0.33	0.072	0.048	0.036	0.02
June 16-30	0.01	0.30	0.10	0.275	0.06	0.04	0.03	0.01
July 1-15	0.01	0.20	0.08	0.18	0.048	0.032	0.024	0.01
July 16-31	0.01	0.12	0.06	0.10	0.032	0.024	0.02	0.01
Aug. 1-15	0.01	0.08	0.036	0.07	0.024	0.016	0.016	0.01
Aug. 16-31	0.01	0.08	0.036	0.07	0.024	0.016	0.016	0.01
Sept. 1-30	0.01	0.10	0.03	0.09	0.03	0.016	0.016	0.01
Oct. 1-15	0.01	0.12	0.04	0.11	0.036	0.024	0.016	0.01
Oct. 16-Nov. 1-10	0.01	0.36	0.12	0.33	0.072	0.048	0.036	0.01

IMAGE EVALUATION
TEST TARGET (QA-3)

150mm

6"

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