

**APPENDIX 1:**  
**CALIBRATION OF WATER QUALITY MODELS FOR THE  
OPEN-WATER SEASON OF 2002.**



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## 1.0 INTRODUCTION

The Assiniboine River monitoring study was initiated in 1998 to assess the effects of effluent from the Maple Leaf (ML) Industrial Waste Water Treatment Facility (IWWTF), in conjunction with other effluent discharges at Brandon, on water quality in the Assiniboine River. As part of this study, water quality models of the Assiniboine River downstream of the City of Brandon to the reservoir at Portage la Prairie were developed to: (1) facilitate predictions of effects of varying effluent discharges on water quality under varying flow conditions; and, (2) evaluate the effect of potential future development in the study area on water quality.

Initially, major water quality parameters that were identified for evaluation via modeling, included: dissolved ammonia nitrogen; dissolved oxygen (DO); carbonaceous biochemical oxygen demand (CBOD); nitrogen (N) and phosphorus (P) compounds; algae (i.e., phytoplankton); and, fecal coliform bacteria. Ammonia was identified as a concern because in high concentrations it is toxic to aquatic biota. DO and CBOD were monitored because decreases in DO may be harmful to aquatic biota. The need to evaluate nitrogen and phosphorus compounds in the Assiniboine River was related to the potential for effluents to cause eutrophication in the river, which may include the development of nuisance algal blooms. Fecal coliform bacteria were identified as a concern because elevated concentrations of fecal coliform bacteria may impinge upon the recreational quality of the area. However, because concentrations of fecal coliform bacteria measured during the monitoring programs were low, monitoring and modeling of this parameter was discontinued for the 2002 sampling program.

Development of water quality models for open-water and ice-cover seasons in the Assiniboine River was conducted using the Enhanced Stream Water Quality Model (QUAL2E) version 3.0, supported and distributed by the U.S. Environmental Protection Agency (Cooley et al. 2001a and 2001b). QUAL2E (or earlier versions of the modelling program) has been extensively used for simulating water quality conditions in well-mixed dendritic streams, for predictive purposes and as a management tool. Systems that have been modelled using QUAL2E (or earlier versions) include: the Red River of the North in North Dakota (Wesolowski 1994, 1996); the River Blackwater, England (Crabtree et al. 1986); the Kali River, India (Ghosh and McBean 1998); the Blackstone River, U.S. (Chaudhury et al. 1998); the Saint-Charles River, Quebec (Vescovi et al. 1999); the Whippany River, New Jersey (Van Orden and Uchirin 1993); major rivers near Madrid, Spain (Cubillo et al. 1992); the Tualatin River, Oregon (Rounds and Wood 2001); the Karasu River, Turkey (Uluatam 1993); approximately 30 rivers in Poland (Gromiec 1997); the Willamette River, Oregon (DeGasperi and Khangaonkar 1997); and, the River Sava, Slovenia (Drovc and Koncan 1996, 1999).

Water quality data were collected through intensive sampling programs designed to follow a parcel of water as it traveled down the river from the City of Brandon to the reservoir at Portage la Prairie. These intensive sampling programs were conducted in May, June, July, August, and September, 1999, May and June 2000, and June, July, and August/September 2002; data collected during these sampling programs are presented in Toews et al. (1999), Toews et al. (2000), and Toews (2002). However, high river discharge during the open-water season in 1999 resulted in rapid dilution of effluents, rendering these data of limited usefulness for model calibration or verification. The sampling program in 2000 was suspended after the June sampling due to flood conditions in the study area and was deferred until such time that low flows occurred. Low river discharge during the open-water season of 2002 provided the opportunity to complete collection of water quality data for model calibration.

Results of initial model calibration exercises based on data collected in May and June 2000 are presented in Cooley et al. (2001a); a calibrated model for the ice-cover season was presented in Cooley et al. (2001b). This report presents results of attempts to calibrate open-water models for the Assiniboine River from the City of Brandon to the reservoir in Portage la Prairie, based on data collected in June, July, and August/September 2002.

## 2.0 SAMPLING PERIODS

Data were collected during three intensive monitoring periods in 2002: (1) June 03-18; (2) July 15-July 26; and, (3) August 20-September 03. In general, river discharge was low in the open-water season of 2002, permitting evaluation of the effects of effluent discharges on water quality during periods of low flow. Detailed descriptions of methods and results of these sampling periods are presented in Toews (2002). The study area and locations of sampling sites are provided in Figure 1. The following provides background regarding the environmental conditions that occurred during sampling.

### 2.1 ENVIRONMENTAL CONDITIONS DURING SAMPLING PERIODS

#### 2.1.1 June 2002

Flows in the Assiniboine and Souris Rivers at the start of the June sampling period were near lower decile levels (Figures 2-4). However, heavy rain beginning 8 June created substantial runoff and elevated river discharge, particularly in the Assiniboine River. Due to the spatial variability of the heavy rain events, accurate estimates of discharge in portions of the river downstream of Site 9 at the time of sampling were difficult to determine. High flows in small tributaries and visibly elevated suspended sediment in tributaries and in the Assiniboine River were observed during sampling in the downstream end of the study reach.

#### 2.1.2 July 2002

Weather during the July sampling period was mainly clear with daytime high temperatures between approximately 26EC and 30EC. Water temperatures were also atypically high during the July sampling period, ranging from 22.8 to 29.4 °C. For comparison, the maximum observed water temperature at the Mnatioba Conservation water quality monitoring station at Brandon for the month of July over the period of 1993 to 2002 was 22.5 °C and the median temperature for the same period is 19.8 °C. Heavy rain at and upstream of Brandon during the week prior to the sampling period produced a crest of approximately 30 m<sup>3</sup>/s in the Assiniboine River (<http://www.gov.mb.ca/conservation/watres/index.html> 12 July 2002). Sampling coincided with the tail end of this crest from Brandon to Portage la Prairie (Figures 2 and 3). During this period, the Souris River discharge was above the median level due to heavy rains in the U.S. portion of the watershed in June.

### 2.1.3 August/September 2002

As with the previous two sampling periods, heavy rain preceded the late August/early September sampling period, with 25 - 50 mm of rain falling within the study area between 16 and 18 August. From 20 to 28 August, the weather was generally clear (except for 21 August), with morning low temperatures between 9EC and 14EC, and highs between 23EC and 31EC. The weather on 28 - 31 August was cooler and overcast with thundershowers, and from 3 to 5 September was clear with high temperatures 23 - 25EC.

The August/September sampling period took place during a period of increasing flows in the Assiniboine River due to preceding heavy rainfall and increases in water release from the Shellmouth and Rivers reservoirs in early August. At the time of sampling, Assiniboine River discharge was approaching the median level (Figures 2 and 3). Discharge in the Souris River, however, had been reduced in late July, and was near the lower decile at the time of sampling (Figure 4).

## 2.2 MODEL DESCRIPTION AND COMPONENTS

QUAL2E is a one-dimensional, steady-state, stream water quality model which simulates up to 15 water quality parameters based on advection-dispersion processes, mass-transport equations, and biological processes. The model requires division of the study area into stream reaches with uniform hydraulic characteristics. In turn, each reach is sub-divided into computational elements of equal length, which are treated as fully mixed river segments that are linked to one another via dispersion and advection.

Tributary streams are designated as a 'junctional element' at the confluence of the two systems. Discharge and water quality variables (i.e., corresponding loads of water quality substances) from the tributary stream are then incorporated into the hydraulic and water quality model for the main stream (i.e., the Assiniboine River). Headwaters, which in this case refer to the upstream end of the Assiniboine River, are designated as 'headwater elements'.

QUAL2E accommodates 50 stream reaches, 20 computational elements within a reach, 10 headwater elements (up to a total of 500 elements), 9 junction elements, and a total of 50 point sources or withdrawals. Up to 15 water quality constituents can be modeled using QUAL2E, including: BOD, DO, nitrate, nitrite, ammonia, organic nitrogen, chlorophyll *a*, temperature,

dissolved phosphate, organic phosphate, coliforms, one non-conservative substance, and up to 3 conservative substances.

### **2.3 RIVER SEGMENTATION**

The open-water model of the Assiniboine River consists of 44 stream reaches of varying lengths and a total of 290 computational elements, each 1 km in length (Table 1). The model begins approximately 250 m downstream of the 18<sup>th</sup> Street Bridge in the City of Brandon and extends approximately 287 km downstream to the reservoir at Portage la Prairie. Stream reaches were selected according to stretches of river with similar or uniform hydraulic characteristics, with consideration granted to locations of effluent outfalls and the confluence of the Souris River. The Souris River is treated as a tributary stream with the confluence designated as a 'junction element' at segments 22/23, approximately 61 km downstream of the 18<sup>th</sup> Street Bridge. The Souris River is allotted one river reach, with three computational elements. Other tributaries that were sampled in the intensive monitoring program of 2002 were included in the models as point sources, where flow was observed at the time of sampling.

### **2.4 RIVER DISCHARGES**

River discharges are routinely measured in the Assiniboine River at the City of Brandon and Holland and on the Souris River at Wawanesa. Daily discharges were obtained and the appropriate discharges for the June, July, and August/September 2002 sampling periods were selected for model calibration (Table 2).

For all model simulations, the effluent discharge from the Brandon Municipal wastewater treatment facility (WWTF) was subtracted from the discharge reported for the Assiniboine River at Brandon, to account for water withdrawal that occurs downstream of the stream gauging station at Brandon. This river discharge is returned to the Assiniboine River via the discharge of effluents from the Municipal WWTF, approximately 16.6 km downstream of the 18<sup>th</sup> Street Bridge in Brandon.

## 2.5 HYDRAULIC DATA

In QUAL2E, hydraulic characteristics may vary between model reaches, but are constant within each reach (i.e., computational elements within a given reach are assigned the same hydraulic characteristics). The preliminary assessment relied upon hydraulic data derived from two river cross sections (Lawrence and Bernhardt 1998). A detailed hydraulic model of the Assiniboine River for the open-water season was derived in 1999 and further modified up to 2002 by Earth Tech Canada (Reid Crowther & Partners Ltd. 1999). The hydraulic model was used to generate coefficients and exponents for depth, velocity, and roughness (i.e., Manning's roughness coefficients) and longitudinal dispersion coefficients that were entered into the model for each reach. As indicated previously, the model segmentation was designed to account for stretches of river with similar hydraulic characteristics. These coefficients and exponents are used internally within QUAL2E to derive actual values for discharge, depth, velocity, travel time, dispersion, width, and ultimately advection and mass transport of relevant water quality parameters.

Values for the dispersion constants and Manning's roughness coefficients are specific to a given discharge scenario and vary according to the period being simulated. Longitudinal dispersion constants were calculated by Earth Tech Canada Ltd. based on hydraulic characteristics, such as velocity, width, depth, channel slope, and shear velocity. Methods for the derivation of longitudinal dispersion constants are provided in Reid Crowther & Partners Ltd. (1999).

Values for incremental flow, cumulative discharge, Manning's roughness coefficient, and longitudinal dispersion constants for the June, July, and August/September 2002 sampling periods are presented in Tables 3 to 5, respectively.

### 2.5.1 River Travel Times

River travel times are estimated on the basis of velocities, and are derived from the hydraulic model. Prior to the conduct of the water sampling programs, travel time estimates were generated using the then current hydraulic model in order to determine appropriate sampling times. Collection of water samples in the Assiniboine River (and Souris River) was staggered in accordance with estimated river travel times generated with the then current hydraulic model, in an attempt to ensure that the same parcel of water was sampled as it travelled downstream from Brandon.

## 2.6 POINT SOURCES: EFFLUENT DISCHARGES

There are three main sources of effluent discharges within the study area: (1) the municipal drainage ditch that receives discharge from the Simplot Canada Ltd. fertilizer plant and the Manitoba Hydro Thermal Generating Station ash lagoon; (2) the City of Brandon Municipal WWTF (cells 3 and 5); and, (3) the Maple Leaf Meats IWWTF. Effluents from the Brandon Municipal WWTF are discharged year-round through cells 3 and/or 5. These outfalls are located in model reaches 10 and 11, respectively. Effluents from the ML IWWTF are discharged into the Assiniboine River approximately 17 km downstream of the 18<sup>th</sup> Street Bridge, which corresponds to model reach 11.

Discharge from the municipal drainage ditch that receives discharge from the Simplot Canada Ltd. fertilizer plant and the Manitoba Hydro Thermal Generating Station ash lagoon has been observed year-round; during the summer months (May 16 - September 14) the municipal ditch, which is located in model reach 7, does not receive effluent from Simplot Canada. However, measurement of water chemistry at the end of the ditch in the open-water seasons of 1999 and 2000 revealed it to be a significant source of nutrients year-round. Therefore, data were also collected for this source in 2002.

Effluent discharges (or other point sources) are indicated as to their location in the model segmentation scheme in Table 1. Effluent quality and discharge rates for the City of Brandon WWTF and the Maple Leaf IWWTF and water quality and discharge measured at the end of the municipal drainage ditch that receives discharge from the Simplot Canada Ltd. Fertilizer Plant and the Manitoba Hydro Thermal Generating Station ash lagoon for the June, July, and August/September 2002 sampling periods are presented in Tables 6 to 8, respectively. Effluent quality data for the Municipal WWTF and the Maple Leaf IWWTF, provided by the City of Brandon, for the open-water season of 2002 are presented in Tables 9 and 10.

## 2.7 TRIBUTARIES

The major tributary within the study area is the Souris River. The confluence (or junction) of the Souris River and the Assiniboine River occurs at the lower end of model reach 22 (Table 1). Water quality data collected during the associated monitoring period at sampling site 8A (i.e., in the Souris River) were entered into the model (Tables 6-8).

## 2.8 UPSTREAM WATER QUALITY DATA

QUAL2E requires specification of concentrations of water quality constituents at the upstream (or boundary) end of the study area. For the purposes of calibration, concentrations of various physico-chemical variables for the upper boundary of the model were derived from measurements taken at sampling site 2, during the monitoring periods of 2002 (Table 11).

## 2.9 GROUNDWATER AND OTHER SOURCES OF FLOW

River discharge in the study area is comprised largely of upstream (i.e., incoming) river discharge and inflow from the Souris River. In addition, the Assiniboine River between Brandon and Portage la Prairie receives inputs of groundwater, flow from a number of drains and tributaries, non-point source runoff, and precipitation. Flow distribution was determined by subtracting the combined flows of the Assiniboine River measured at Brandon and the discharge of the Souris River, measured at Wawanesa, from the flow measured at Holland. This 'remaining flow' is a conglomeration of discharge of other tributary streams in the area, groundwater, surface runoff, and precipitation.

The Assiniboine River receives a substantive volume of groundwater within the study area. Flows of groundwater were distributed, as a component of the hydraulic model, along the river from model reach 10, corresponding to a downstream distance of approximately 16 km, through river reach 38 (approximately 224 km downstream), in which sampling site 12 is located (Table 1). Volumes of groundwater allocated in the study area were based upon the difference in discharge between the combined flows of the Souris River and the Assiniboine River at Brandon and the flow rate at Holland. Discharges measured at tributary streams were subtracted from the calculated incremental flows for the corresponding reach. Additional groundwater was added beyond Holland, based on knowledge of the aquifer in the study area. Groundwater was added incrementally along the river from model reach 10 through 38. In QUAL2E, additional flows, including flow due to groundwater inputs, are entered as 'incremental flows' according to each river reach. Incremental flows for the June, July, and August/September 2002 monitoring periods are presented in Tables 3 to 5, respectively.

A significant fraction of flow is comprised of groundwater from the Carberry aquifer, which is located approximately between cross-sections 44 and 82. The Water Resources Branch of Manitoba Conservation has indicated that the Carberry aquifer would supply an average flow of approximately 3.96 m<sup>3</sup>/s (140 cubic feet per second) to the Assiniboine River. Since there is a

flow measuring station on the Assiniboine River at the PTH 34 bridge, inside the known extents of the Carberry aquifer, this groundwater flow is divided into two sections. The upstream section includes the river upstream of PTH 34, between cross-sections 44 and 72 and, based on the length of the Assiniboine River exposed to the aquifer, is estimated to contribute approximately 3.40 m<sup>3</sup>/s (120 cfs) of groundwater to the river. The downstream section includes the river reach downstream of PTH 34, from cross-section 72 to 82, and contributes an estimated 0.57 m<sup>3</sup>/s (20 cfs) of groundwater to the river. The inputs from the Carberry aquifer were distributed along the stretch of river affected by the aquifer as a per kilometre flow rate.

The remainder of flow includes additional surface water flow from tributaries, other than the Souris River, and groundwater sources that occur outside the Carberry aquifer. The Assiniboine River has flow measuring stations located at the 18th Street bridge in Brandon (Brandon) and at the PTH 34 bridge near Holland (Holland). There is also a flow measuring station located on the Souris River in Wawanesa (Souris). The information obtained from these flow stations is used to determine the remainder of the incremental flow by subtracting the Brandon flow, the Souris flow and the 3.40 m<sup>3</sup>/s (120 cfs) from the aquifer from the Holland flow. The remaining flow is distributed along the river on a per-kilometre basis from cross-section 9 to cross-section 72. In the event that the flow difference results in a negative number, the additional flow is taken as zero. Measured discharges for tributaries and drains were subtracted from the incremental flow for the corresponding river reach, to correct for these sources of discharge. Discharge from these tributaries were entered into the model as point sources (i.e., they are accounted for in a different screen of the model).

In the sampling periods in the open-water season of 2002, incremental flow was composed mainly of groundwater, assuming constant flow from the Carberry aquifer. In June 2002, heavy precipitation events occurred during the sampling period, which contributed an unknown fraction of flow to the Assiniboine River. For the water quality model, it was assumed that incremental flow did not contribute nitrogen or phosphorus to the river.

## 2.10 RATE PROCESSES, KINETICS, AND CONSTANTS

In QUAL2E, all processes, whether they be chemical, physical, or biological, that affect nutrient, DO, or phytoplankton dynamics are expressed as rates and are corrected for temperature using a temperature correction factor. The same basic equation, a ‘Streeter–Phelps type of formulation’, applies to all rate processes relevant for the open water model (Brown and Barnwell 1987):

$$X_{TEC} = X_{20EC} 1^{(T-20)EC}$$

Where:  $X_{TEC}$  = the value of the coefficient at the ambient temperature (T)  
 $X_{20EC}$  = the value of the coefficient at the standard temperature (20 °C)  
 $\theta$  = a temperature correction factor for each reaction coefficient

Values for rates and constants used for simulation of nutrients and phytoplankton for June, July, and August/September 2002 that are not reach-variable in QUAL2E are presented in Table 12. Values for rates and constants used for June, July, and August/September 2002, that are reach-variable in QUAL2E are presented in Tables 13 to 15, respectively. Values for the associated temperature correction factors are presented in Table 16.

In general, values used in model simulations fall within the range of values reported in the literature (Bowie et al. 1985; Brown and Barnwell 1987). However, it is recognized that values for the various rate processes were assigned in attempts to calibrate the water quality model in the absence of a component to simulate periphyton. As such, it is important to recognize that these values may prove to be inappropriate if periphyton were incorporated into a model for the study area.

## 2.11 MASS BALANCE SIMULATIONS

QUAL2E was used to simulate total nitrogen, total phosphorus, total suspended solids (TSS), and conductivity in the Assiniboine River in the open-water season as mass-balance relationships. This is accomplished in QUAL2E by simulating these parameters as 'conservative substances' (i.e., there is no decay or production of these parameters).

With respect to nutrients, this undertaking facilitated examination of the overall loss or gain of nutrients in the study area. This provides some insight into the overall dynamics of nitrogen and phosphorus in surface waters and indicates the presence of potential sources of nutrients as well as the potential loss of nutrients due to processes such as accumulation by periphyton and aquatic macrophytes and/or settling.

Modelling conductivity as a conservative substance provides some indication of the accuracy of the model, particularly with respect to hydraulics. Ideally, a perfect match between observed and simulated conductivities would indicate that the river discharges were accurate and that the loads from all potential sources were accurate.

TSS was simulated as a mass-balance to provide an assessment of potential settling (i.e., deposition) of particulate matter and the presence and locations of potential sediment scouring. Underpredicting TSS may also indicate the presence of point or non-point flow in the study area. Ultimately, this information assists in the calibration of the models for nutrients and phytoplankton as it may provide some indications of areas that may be affected by river processes that can not be simulated (i.e., phosphorus may increase due to suspension of sediments).

### 3.0

## RESULTS

Model calibration results for June, July, and August/September 2002 are presented in the following sections.

### 3.1 RIVER HYDRAULICS

Simulated river discharges and velocities for June 2002 are presented in Figures 5 and 6, respectively. Simulated river discharges and velocities for July 2002 are presented in Figures 7 and 8, respectively. Simulated river discharges and velocities for August/September 2002 are presented in Figures 9 and 10, respectively.

In general, river velocities were very similar across the sampling periods. Velocities ranged between 0.019 and 1.596 m/s in June, between 0.016 and 1.606 m/s in July, and between 0.013 and 1.573 m/s in August/September 2002.

River discharges were somewhat variable across the sampling periods. In June 2002, a substantive fraction of Assiniboine River flow was comprised of ‘other sources’ of discharge, including tributaries other than the Souris River, groundwater, and to an unknown extent, precipitation and runoff. This ‘other’ flow was estimated to be higher (12.06 m<sup>3</sup>/s) than the Assiniboine River discharge at Brandon (9.9 m<sup>3</sup>/s).

In July, the Souris River discharge had increased significantly and it comprised a significant fraction (31%) of the flow at Holland. Contributions of flow from tributaries other than the Souris River were relatively small during this sampling period. Conditions occurring during the August/September sampling period were somewhat intermediate between the June and July conditions.

### 3.2 TRAVEL TIMES

Simulated travel times and time of sample collection for June, July, and August/September 2002 are presented in Figures 11 to 13, respectively. Sampling times were based on preliminary travel time estimates generated prior to the conduct of the sampling program that were based on river discharge information available at that time. Travel times were revised, following the sampling program, when data were received regarding more precise river discharge estimates. As such,

sampling times did not always correspond to revised river travel time estimates. However, in general, sampling times matched river travel times reasonably closely.

In June 2002, sampling was timed to track a parcel of water that received effluent discharges on June 05, 2002. However, sampling was behind the river, relative to revised travel time estimates, at several locations, including Sites 5, 6, 7, 8, 9, 10, and 14 (Figure 11). Most notably, sampling was conducted approximately 26 hours late at sampling site 10 and 22 hours late at sampling site 14, in the Portage Reservoir. Therefore, samples collected at sites 10 and 14 were samples of water that had received effluents a day or two later (i.e., June 06/07, 2003) than other sampling locations.

In July 2002, sampling was timed to track a parcel of water that received effluents discharged on July 16, 2002. Sampling at most locations closely approximated river travel times (i.e., sampling occurred within several hours of revised travel time estimates). However, sampling at sites 13 and 14 was conducted approximately 21 hours and 66 hours too early, respectively (i.e., sampling was ahead of the river). Therefore, the parcel of water sampled at site 13 had received effluent on July 15 and the parcel of water sampled at site 14 had received effluent on July 13/14, 2002.

In August/September 2002, sampling was timed to track a parcel of water that received effluent discharges on August 21, 2002. However, sampling was behind the river, relative to revised travel time estimates, at many locations, including Sites 8-14 (Figure 13). Most notably, sampling was conducted approximately 30 hours late at sampling site 13 and 40 hours late at sampling site 14, in the Portage Reservoir. Therefore, samples collected at sites 13 and 14 were samples of water that had received effluents a day or two later (i.e., August 22/23, 2002) than other sampling locations. Discrepancies between sampling and river travel times is most critical when conditions fluctuate widely, with respect to effluent loads, river discharges, and flow from tributaries.

### **3.3 MASS-BALANCE SIMULATIONS**

Mass-balance simulations were conducted for specific conductance, TSS, and total nitrogen and phosphorus to evaluate the occurrence of potential sources and losses of substances in the study area. This was undertaken by modeling these parameters as conservative substances, where the concentration in the river is governed only by dilution and loading from designated sources (i.e.,

a mass-balance). Simulation results were then compared to measured concentrations of the substances to evaluate potential dynamics in the study area.

Conductivity is often used as a tracer to evaluate the accuracy of hydraulic models. TSS was examined to assess the potential occurrence of sediment resuspension in the study area and/or potential sources of TSS (and other substances) that were not accounted for in the water quality sampling program. In this context, TSS is used as an indicator of the presence of potential sources for other substances, such as nutrients, because an increase in TSS above model simulation results may indicate a point source, a non-point source, and/or sediment resuspension, all of which may be potential sources of nutrients, BOD, TSS, and algae. Total nitrogen and phosphorus were simulated as conservative substances to evaluate the potential sources and sinks for nutrients in the study area (e.g., to determine whether substantive losses of nutrients occur in the study area).

### **3.3.1 Specific Conductance**

Specific conductance, which is temperature-standardized conductivity, was simulated as a conservative substance for the June, July, and August/September 2002 periods to evaluate the accuracy of the hydraulic model and the potential loadings to the Assiniboine River. Results of these simulations are presented in Figures 14-16.

Simulated conductivities were underestimated in all periods, relative to measured values. This may indicate that river hydraulics/discharge were not accurately represented in the model or that loading to the river was underestimated. Groundwater is known to contribute some fraction of conductivity (and associated substances) to the Assiniboine River, as indicated by measurements collected at emergent springs in the open-water season of 2002. However, the specific conductance of the two springs sampled was considerably lower than measured in the Assiniboine River and it is not known to what extent these isolated measurements represent the overall contribution of groundwater in the entire study area to conductivity in the Assiniboine River. Nonetheless, it should be noted that the underestimation of the model with respect to conductivity is, to an unknown extent, affected by not accounting for this source.

### **3.3.2 TSS**

TSS was simulated as a conservative substance for the June, July, and August/September 2002 periods to assess the potential occurrence of sediment resuspension and/or areas of substantive deposition in the study area. Discrepancies between model simulations and measured values

may indicate areas of scouring and/or point or non-point sources that were not captured in the sampling programs conducted in 2002 and may indicate areas where velocities were sufficient to result in measurable settling.

In all periods examined, simulated TSS was reasonably approximated in the upper end of the study area by a mass-balance relationship. However, for all sampling periods, TSS was considerably underestimated by a mass-balance simulation at sites 11, 12, and 13 (Figures 17-19). This may indicate the occurrence of sediment resuspension in this stretch of the river and/or the presence of other sources of TSS, such as tributary streams that were not sampled in 2002 or non-point sources (e.g., surface runoff). Increases in TSS, as observed at these sites, may also indicate potential sources of nutrients and BOD, as sediment resuspension and or point and non-point sources would also result in the introduction of organic matter and nutrients to the water column. Mass balance model simulations for total nitrogen and total phosphorus indicated that there may have been a nutrient source at sites 11 to 13 at some times (See Section 4.3.3).

### **3.3.3 Nitrogen and Phosphorus**

QUAL2E was used to simulate concentrations of total nitrogen and total phosphorus in the Assiniboine River, under the discharges that occurred in June, July, and August/September 2002 and, using a mass-balance approach. The results were then compared to observed concentrations (and loads) of total nitrogen and phosphorus to evaluate potential sites and magnitude of nutrient losses from (or gains to) the water column. Results are presented in Figures 20-25. In-stream loads for total nitrogen and phosphorus were also calculated for these substances using modeled data (mass balance simulations) and measured data, in conjunction with simulated river discharges (Figures 26-31). Comparisons of calculated loads of nitrogen and phosphorus and results of mass-balance simulations are summarized in Tables 17 to 22.

## **3.4 JUNE 2002 SIMULATIONS: NUTRIENTS, CHLOROPHYLL *a*, AND DISSOLVED OXYGEN**

The model calibration exercise for the June 2002 monitoring period approximated measured concentrations of total phosphorus (Figure 32), dissolved phosphorus (Figure 33), organic phosphorus (Figure 34), total nitrogen (Figure 35), ammonia (Figure 36), nitrate/nitrite (Figure 37), organic nitrogen (Figure 38), and chlorophyll *a* (Figure 39) reasonably well. A summary of loads of total nitrogen and phosphorus discharged from the WWTF, the IWWTF, and the municipal drainage ditch during the June sampling period is provided in Table 23.

### 3.4.1 Phosphorus

Simulated and measured total phosphorus, dissolved phosphorus, and organic phosphorus, for June 2002 are presented in Figures 32 to 34.

Model simulation results were in good agreement with observed concentrations of total, dissolved, and organic phosphorus at most sites. The exceptions were sites 11 to 13, where measured concentrations of total and organic phosphorus were substantively higher than simulated values. However, model simulation results for site 14 were also consistent with measured values. Dissolved phosphorus was well represented by the model at all locations. Collectively, these observations indicate that there may have been a source of organic phosphorus in the downstream end of the study area. Similarly, a source for TSS is also indicated by mass-balance simulations for these areas. The observed decline between site 13 and 14 may indicate settling of particulate matter in the reservoir, which is consistent with observed dynamics for TSS.

Possible sources of organic phosphorus include sediment resuspension, a point source not captured by the sampling program, non-point sources or inaccurate representation of loads of organic phosphorus in tributaries that were sampled in June 2002. The measured concentration of organic phosphorus along the left channel, downstream of the Cypress River, was considerably high. It is possible that measured loads of organic phosphorus from the Cypress River were underestimated during the sampling program. Discharge from the Cypress River was quite high in June ( $1.84 \text{ m}^3/\text{s}$ ), which exceeded the discharge from the major tributary in the study area, the Souris River ( $1.16 \text{ m}^3/\text{s}$ ). The discharge may have been sufficient to result in scouring of sediments in the Assiniboine River, thus introducing organic phosphorus, TSS, and possibly organic nitrogen (see Section 4.4.2) to the water column.

### 3.4.2 Nitrogen

Simulated and measured concentrations of total nitrogen, ammonia, nitrate/nitrite, and organic nitrogen for June 2002 are presented in Figures 35-38.

In general, model simulation results agreed relatively well with measured concentrations of nitrogenous compounds. Incorporation of settling of organic nitrogen and accumulation of dissolved nitrogenous species (i.e., nitrate/nitrite and ammonia) by phytoplankton, which reduce the concentration of nitrogen in the water column, into the model resulted in a good match between simulated and measured total nitrogen concentrations in the mixing zone (Figure 35).

The mass-balance simulation overestimated total nitrogen at these sites, indicating the presence of sinks. However, the model underestimated total nitrogen at sites 11 and 12, possibly suggesting a local source.

Model simulations slightly underestimated ammonia in the mixing zone but overestimated nitrate/nitrite (Figures 36 and 37). However, both species were reasonably well approximated by the model at the downstream end of the study area. The discrepancies between the model and observed concentrations in the mixing zone may indicate accumulation of the bioavailable dissolved forms of nitrogen by aquatic plants and algae that are not simulated by the model (i.e., periphyton).

Conversely, organic nitrogen was underestimated by the model, particularly at sites 10 to 12 (Figure 38). However, these discrepancies may indicate the presence of a source of organic nitrogen at the downstream end of the study area, as appears to be the case for organic phosphorus.

### **3.4.3 Chlorophyll *a***

Model simulations approximated observed concentrations of chlorophyll *a* at most locations for the June 2002 period. However, the model underpredicted the peak concentrations observed downstream of the effluent outfalls. The model was unable to simulate the rapid decline in nitrate/nitrite observed in the mixing zone, at the levels of chlorophyll *a* that were simulated.

As observed for organic and total phosphorus, TSS, and organic and total nitrogen, modelling results underestimated chlorophyll *a* by a substantive margin at sites 11 to 13 (Figure 39). Collectively, these observations indicate a possible source of organic matter in this portion of the study area in June 2002. As discussed above, this may reflect possible resuspension of sediments and associated algae.

## **3.5 JULY 2002 SIMULATIONS: NUTRIENTS, CHLOROPHYLL *a*, AND DISSOLVED OXYGEN**

The model calibration results for the July 2002 monitoring period approximated measured concentrations of total phosphorus (Figure 40), dissolved phosphorus (Figure 41), organic phosphorus (Figure 42), chlorophyll *a* (Figure 43), ammonia (Figure 44), and organic nitrogen (Figure 45), but overestimated total nitrogen (Figure 46) and nitrate/nitrite (Figure 47).

### 3.5.1 Phosphorus

Simulated and measured total phosphorus, dissolved phosphorus, and organic phosphorus for July 2002 are presented in Figures 40 to 42.

Model simulation results approximated total phosphorus and dissolved phosphorus concentrations measured during the monitoring study, particularly downstream of the mixing zone. Organic phosphorus was less accurately simulated for the July 2002 sampling period by the model. In general, total, dissolved, and organic phosphorus were overestimated in the mixing zone, possibly reflecting the presence of a sink for phosphorus not accounted for by the model or due to inaccurate loading data. Loads of total phosphorus discharged by the Brandon Municipal WWTF, the Maple Leaf IWWTF, and the Municipal Drainage Ditch were reduced by approximately one half from July 16 to July 17, 2002; loads were similar on July 15 and 16, 2002. Similarly, loads of total phosphorus from the Brandon WWTF and the ML IWWTF measured on July 10, 2002 (Tables 9 and 10) were similar to those measured on July 15 and 16, during the monitoring study (Table 24). As the model, and the collection of water samples, were constructed for effluent discharged on July 16, any departures in river sampling times relative to river travel times may have affected model simulation results. In other words, where sampling fell behind the river, water samples would have received effluent with lower loads of total phosphorus. However, sampling times were in relatively good agreement with river travel times at most sites. The major exception was site 14, where sampling was conducted approximately 3 days too early. Collectively, the results of the model simulations for phosphorus indicate a potential sink for phosphorus in the mixing zone. Possibilities include uptake by algae (i.e., periphyton) and aquatic plants that are not simulated by the model or a physical process such as settling.

### 3.5.2 Nitrogen

Total nitrogen and nitrate/nitrite nitrogen were overestimated by the model at most sites in the study area for the July 2002 period. In general, concentrations were overestimated in the mixing zone, with better replication of observed concentrations in the downstream end of the study area. Ammonia and organic nitrogen were slightly overestimated in the mixing zone by the model but simulations were in good agreement with observed concentrations in the downstream end. Model simulations overestimated the load of nitrogen in the river, downstream of sampling site 3 and the outfalls for the Brandon Municipal WWTF and the ML IWWTF. This discrepancy may indicate that loads of total nitrogen discharged from these sources were overestimated during the monitoring period. As a result of this overestimation, total nitrogen concentrations were

overestimated by model simulations throughout the study area, downstream of these effluent outfalls in July 2002. Conversely, if the modeled loads were indeed accurate, the discrepancies between model simulation results and observed concentrations of total nitrogen indicate a possible substantive sink in the mixing zone, as was indicated by the June 2002 results.

As observed for June 2002, model simulations indicate that the concentration of phytoplankton (i.e., chlorophyll *a*) that occurred in July 2002 were insufficient to account for the observed loss of nitrogen in the river. Also like June 2002, model simulation results were similar to measured values for organic nitrogen and approached measured values for ammonia. However, model simulation results for nitrate/nitrite were much higher than observed values. These comparisons further support the suggestion that periphyton may have played a significant role in removing nutrients (i.e., bioavailable forms of nitrogen) from surface water, particularly in the mixing zone.

### **3.5.3 Chlorophyll *a***

Simulated and measured chlorophyll *a* concentrations for July 2002 are presented in Figure 43. The model was calibrated reasonably well for concentrations of chlorophyll *a* observed in July 2002. However, chlorophyll *a* concentrations did not follow a regular pattern along the length of the study area. Water temperatures that occurred during the conduct of the monitoring program in July were high (ranging from approximately 22 °C to 29 °C) and may have approached lethal temperatures for phytoplankton during some periods. For comparison, the maximum observed water temperature measured in the Assiniboine River at the Manitoba Conservation water quality monitoring station at Brandon for the period from 1993 to 2002 was 22.5 °C. Higher concentrations of pheophytin were also observed in water samples collected in July 2002, relative to June 2002, indicating a fairly high rate of phytoplankton degradation (Toews 2002). Therefore, conditions that occurred during this monitoring period may have been exceptional and may have affected patterns of phytoplankton growth and subsequently, nutrient dynamics, in the study area.

## **3.6 AUGUST/SEPTEMBER 2002 SIMULATIONS: NUTRIENTS, CHLOROPHYLL *a*, AND DISSOLVED OXYGEN**

The model calibration exercise for the June 2002 monitoring period approximated measured concentrations of total phosphorus (Figure 48), dissolved phosphorus (Figure 49), organic

phosphorus (Figure 50), total nitrogen (Figure 51), ammonia (Figure 52), nitrate/nitrite (Figure 53), organic nitrogen (Figure 54), and chlorophyll *a* (Figure 55) reasonably well.

### 3.6.1 Phosphorus

Simulated and measured total phosphorus, dissolved phosphorus, and organic phosphorus, for August/September 2002 are presented in Figures 48 to 50.

Model simulation results overestimated total phosphorus in the mixing zone. Simulations results more closely resembled observed concentrations of total phosphorus at sites 11 to 13, and to a lesser extent, site 14. However, as the loading was misrepresented by the model in the mixing zone, model simulation results downstream do not accurately reflect river conditions. That is, if the model had accurately represented total phosphorus in the mixing zone, model simulation results would have grossly underestimated total phosphorus in the downstream end of the study area. Evaluation of in-stream loads of total phosphorus indicate that loads decrease substantively downstream of site 6 and actually increase at sites 11 to 13 (Figure 31). Conversely, mass-balance simulations indicate that in-stream loads of total phosphorus should remain relatively constant in the downstream end of the study area.

Collectively, these results indicate that there is measurable loss of phosphorus in the mixing zone, as observed in other sampling months and years, and a potential source of phosphorus somewhere downstream of Site 9 and/or 10. Discrepancies between sampling and river travel times do not appear adequate to account for these observations. For example, sampling times were very similar to river travel times in the mixing zone. Furthermore, loads of total phosphorus discharged from the three major sources (i.e., Brandon WWTF effluent, ML IWWTF effluent, and the Municipal Drainage Ditch) did not vary substantively from August 20 to 22 (Table 25). Evaluation of the in-stream loads of phosphorus indicate a loss of approximately 65 kg from site 2 to site 8 (Table 21), which is much higher than the observed variation in effluent loading (Table 25).

Similarly, the model overestimated dissolved phosphorus in the mixing zone and downstream, although the simulated profile along the river (i.e., the shape of the curve) approximated the observed profile. Simulations of organic phosphorus did not with measured concentrations in the mixing zone or at sites 11 to 13.

### 3.6.2 Nitrogen

Simulated and measured concentrations of total nitrogen, ammonia, nitrate/nitrite, and organic nitrogen for August/September 2002 are presented in Figures 51-54.

In general, model simulation results overestimated total nitrogen and nitrate/nitrite and to a lesser extent, ammonia, throughout the study area. By site 8, mass-balance model simulation results indicated an in-stream load of total nitrogen approximately 680 kg higher than the observed load. Because sampling was slightly behind the river, corresponding effluent loads for some of the sites may have fallen somewhere between August 21 and 22; model simulations were based on effluent loads discharged on August 21. As effluent loads of total nitrogen were higher on August 21 than 22 (Table 25), this discrepancy may explain part of the difference between model simulation results and observed loads/concentrations. However, this explanation is not adequate to account for the large difference in simulated vs. measured loads of total nitrogen. Furthermore, incorporation of algae and subsequent loss of nutrients from the water column through algal settling, was inadequate to account for the observed losses of nitrogen. Therefore, based on the model simulation results, it appears that a substantive load of nitrogen is lost in the mixing zone. In particular, as observed in the open-water season 2000 (Cooley et al. 2001b), the dissolved fraction of nitrogen appears to be lost in the mixing zone.

Model simulations slightly overestimated ammonia in the mixing zone but were fairly close to observed concentrations in the downstream end of the study area. Conversely, nitrate/nitrite was grossly overestimated by the model at all sites. This discrepancy occurred despite the allocation of a low algal ammonia preference factor (0.5). The discrepancies between the modelled and observed concentrations may indicate accumulation of the bioavailable dissolved forms of nitrogen by aquatic plants and algae that are not simulated by the model (e.g., periphyton), as has been suggested previously (Cooley et al. 2000b).

### 3.6.3 Chlorophyll *a*

Model simulations approximated observed concentrations of chlorophyll *a* at most locations for the August/September 2002 period (Figure 55). However, simulation of algae, and the associated accumulation of dissolved nutrients, was insufficient to match observed concentrations of ammonia, nitrate/nitrite, and dissolved phosphorus. Settling of phytoplankton was also insufficient to reduce the observed losses of total nitrogen and phosphorus in the river. These observations may indicate a second, unaccounted for, sink for nutrients, such as periphyton and/or aquatic macrophytes.

## 4.0

## DISCUSSION

As Scrimgeour and Chambers (2000) stated, while there has been substantive effort directed at research on effects of eutrophication in and development of water quality models for lakes, the ability to predict effects of nutrient additions on streams and rivers is extremely limited. These deficiencies are illustrated by the limited availability of water quality models that are applicable to nutrient-rich streams. Examination of observed data, in conjunction with model simulation results, indicate that in the Assiniboine River, periphyton (attached algae) may play a major role in nutrient dynamics, particularly in the mixing zone. However, QUAL2E does not currently incorporate a periphyton component.

Calibration exercises for the monitoring periods of June, July, and August/September 2002, as described in previous sections, were reasonably successful. The model calibration for the June 2002 period was particularly successful. There are a number of possible reasons for the inability to calibrate the July and August/September models for some parameters, in particular nitrate/nitrite nitrogen, including:

- Lack of a sink for nutrients in the mixing zone: all modeling exercises for the 2002 period, particularly for the July and August/September periods, indicated the presence of a sink for nutrients in the mixing zone. The QUAL2E model does not incorporate a sink for uptake of nutrients by periphyton or aquatic macrophytes; the only ‘sinks’ are uptake by phytoplankton and subsequent settling of phytoplankton or settling of organic forms of nutrients.
- Inappropriate/inaccurate hydraulic data and river discharges: if river discharges were not adequately represented, incoming loads of substances would be inaccurately represented, as would dilution processes.
- Inaccurate river travel time estimates: if river travel times were not accurate, the sampling program would not have been conducted such that the same parcel of water were tracked down the length of the study area. Subsequently, measured concentrations at various sites would reflect different river discharges and effluent and tributary loads.
- Sampling variability and analytical error associated with analysis of water quality and stream discharge measurements.

- Inaccurate representation of point and non-point sources: underestimation of loads of nutrients in the downstream end of the study area may reflect either underestimation of tributaries that were sampled during the monitoring periods or the presence of other point or non-point sources not sampled at those times.

Model calibration for the open-water seasons of 2000 and 2002 indicated that nutrients may be lost in the mixing zone to a larger extent than could be accounted for by the model. It was previously suggested that uptake of nutrients periphyton may play a role in these losses, particularly in the mixing zone where periphyton are abundant. Specifically, model simulations calibrated to the concentrations of chlorophyll *a* (i.e., phytoplankton) that were measured in May and June 2000 and July and August/September 2002 indicated the levels of phytoplankton were insufficient to account for the decrease in bioavailable nutrients that was observed in the river, most substantively immediately downstream of effluent outfalls.

QUAL2E simulates the phytoplankton community as a collective whole and no consideration is given to the species composition or relative abundance. This model configuration is significant because it results in treatment of algal dynamics for various species in precisely the same manner. Since there may be considerable variation of algal dynamics, such as growth, respiration, nutrient uptake, and settling rates, between species (Bowie et al. 1985), the use of a single term to describe the entire community may be problematic. In addition, a portion of the chlorophyll *a* measured in water samples collected from the Assiniboine River would be suspended algal biomass from sloughing and scouring of periphyton. Consequently, some portion of the chlorophyll *a* is not phytoplankton. This issue was also raised in calibration of a QUAL2E model for the Willamette River, Oregon (DeGasperi and Khangaonkar 1997); high concentrations of chlorophyll *a* in the stretch of river inhabited by periphyton could not be reproduced by QUAL2E.

The following is a brief discussion of model simulation results for the open-water season 2002, with particular consideration of implications to nutrient and algal dynamics in the Assiniboine River.

#### 4.1 NUTRIENTS AND PHYTOPLANKTON

Calibration exercises for water quality models for the open-water season, using data collected in the open-water season of 2002 indicated that the capability of the QUAL2E model to adequately represent nutrient and algal dynamics in the Assiniboine River may be limited due to the lack of

a component for simulating periphyton. The Assiniboine River is characterized by substantive periphyton growth, particularly in the mixing zone, within the study area. Declines in the in-stream loads of nutrients in the mixing zone have been observed in the open-water season of 2000 and 2002. Comparison to model simulation results using a mass-balance approach confirm that substantive quantities of nutrients are removed from the water column, most notably within the mixing zone. Model simulations that incorporate phytoplankton were insufficient to account for these observed losses, particularly in May and June 2000 and July and August/September 2002. These observations indicate that periphyton may play a significant role in nutrient depletion.

The greatest discrepancies between measured data and model simulations results occur for nitrate/nitrite in July and August/September 2002. Reasons for these large differences include: (1) The model overestimates nitrate/nitrite production due to nitrification of ammonia; (2) Lack of a component for nitrate/nitrite uptake by periphyton; and, (3) Denitrification may have occurred if anaerobic conditions existed in the study area (e.g., at the sediment-water interface during a diurnal DO sag).

## 5.0

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## TABLES AND FIGURES



Table 1. River segmentation, location of effluent inputs, weirs, tributaries, and sampling sites.

Model reach	Reach distance		Number of computational elements	Sampling sites, effluent outfalls, and weirs	Distance downstream (km) <sup>1</sup>	Computational element	Cumulative Computational element
	start km	end km					
1	0	1	1	18th Street Bridge; Sampling Site 1	250 m upstream of reach 1	-	-
2	1	5	4	18th Street Weir	4.9	4	5
3	5	6	1				
4	6	10	4				
5	10	12	2				
6	12	13	1	Hydro Weir	12.7	1	13
				Sampling Site 2	12.8	1	12
				Manitoba Hydro Ash Lagoon / Simplot			
				Canada ditch; Sampling Site 2A	13.6	1	14
7	13	14	1				
8	14	15	1	Sampling Site 3	14.4	1	15
9	15	16	1	Willow Creek	15.2	1	16
				Brandon Municipal Cell 5 outfall	16.6	1	17
				Maple Leaf Meats IWWTFF Effluent Discharge	17.1	1	18
11	17	18	1	Brandon Municipal Cell 3 outfall	17.8	1	18
12	18	19	1				
13	19	20	1	Sampling Site 4	20.0	1	20
14	20	21	1				
15	21	22	1				
16	22	23	1				
17	23	24	1	Sampling Site 5	23.8	1	24
18	24	25	1				
19	25	27	2				
20	27	35	8	Sampling Site 6	27.8	1	28
				Little Souris River	30.8	5	32
21	35	51	16	Sampling Site 7	37.2	3	38
				Drain from southwest upstream of Site 8	51.6	1	52
22	51	61	10	Sampling Site 8	51.8	1	52
				Five-Mile Creek	55.1	5	56
				Junction with the Souris River	60.9	10	61

Table 1. - continued -

Model reach	Reach distance		Number of computational elements	Sampling sites, effluent outfalls, and weirs	Distance downstream (km) <sup>1</sup>	Computational element	Cumulative Computational element
	start km	end km					
Souris:							
23	3	0	3	Sampling Site 8A		3	3
24	61	80	19				
25	80	90	10	Sampling Site 9	80.7	1	81
26	90	94	4				
27	94	108	14				
28	108	115	7				
29	115	135	20	Sampling Site 10 Epinette Creek	115.3 132.9	1 9	116 124
30	135	144	9				
31	144	163	19				
32	163	171	8				
33	171	191	20	Cypress River Sampling Site 11	183 185.0	12 14	183 185
34	191	202	11				
35	202	209	7				
36	209	223	14				
37	223	224	1				
38	224	244	20	Sampling Site 12	224.7	1	225
39	244	264	20				
40	264	266	2	Drain from south	265.5	2	266
41	266	274	8	Sampling Site 13	266.1	1	267
42	274	283	9				
43	283	286	3				
44	286	287	1	Sampling Site 14: Portage Reservoir	287.0	1	287

<sup>1</sup> Distance refers to distance downstream of the starting point of the model study area. The model begins approximately 250 m downstream of the 18th Street Bridge in the City of Brandon.

Table 2. Discharges for the Assiniboine and Souris Rivers used for model calibration, June, July, and August/September 2002. Discharges obtained from Water Resources, Manitoba Conservation.

Sampling Period	Discharge (m <sup>3</sup> /s)			
	Assiniboine River at Brandon	Assiniboine River at Holland	Souris River at Wawanesa	Other Tributaries and Groundwater <sup>1</sup>
June 3-18, 2002	9.9	23.12	1.16	12.06
July 15-26, 2002	10.52	19.52	6.09	2.91
August 20 - September 05, 2002	8.44	16.08	1.42	6.22

<sup>1</sup> Discharges from other tributaries and groundwater are estimated as the difference between Assiniboine River discharge measured at Holland and the upstream river discharge measured at Brandon plus the contribution of flow from the Souris River.

Table 3. Hydraulic data for the Assiniboine River during the June 2002 sampling period.

Reach	start km	end km	Number of computational elements	Incremental Flow (m <sup>3</sup> /s)	Discharge <sup>1</sup> (m <sup>3</sup> /s)	Longitudinal Dispersion Constant (k)	Manning's roughness coefficient (n)
1	287	286	1	0	9.74	1711.0	0.0250
2	286	282	4	0	9.74	967.9	0.0375
3	282	281	1	0	9.74	288.4	0.0525
4	281	277	4	0	9.74	371.1	0.0600
5	277	275	2	0	9.74	514.6	0.0500
6	275	274	1	0	9.74	860.0	0.0345
7	274	273	1	0.06	9.8	802.5	0.0375
8	273	272	1	0.05	9.85	377.8	0.0450
9	272	271	1	0.04	9.91	499.9	0.0450
10	271	270	1	0.08	10.15	389.5	0.0477
11	270	269	1	0.00	10.19	440.3	0.0520
12	269	268	1	0.07	10.26	555.3	0.0415
13	268	267	1	0.04	10.3	105.1	0.0900
14	267	266	1	0.07	10.37	501.5	0.0405
15	266	265	1	0.04	10.41	291.4	0.0535
16	265	264	1	0.04	10.45	273.3	0.0565
17	264	263	1	0.05	10.5	356.5	0.0415
18	263	262	1	0.06	10.56	304.7	0.0592
19	262	260	2	0.27	10.69	489.8	0.0400
20	260	252	8	0.77	10.93	429.5	0.0400
21	252	236	16	0.22	11.65	430.5	0.0440
22	236	226	10	0.72	11.93	341.5	0.0498
23	3	0	3	0	1.16	631.8	0.0390
24	226	207	19	1.47	13.86	638.3	0.0350
25	207	197	10	0.75	15.33	428.8	0.0350
26	197	193	4	0.80	16.2	1497.3	0.0250
27	193	179	14	0.53	16.84	3258.3	0.0150
28	179	172	7	0.54	17.41	630.2	0.0340
29	172	152	20	0.84	17.91	1325.8	0.0245
30	152	143	9	1.07	19.5	498.5	0.0400
31	143	124	19	1.08	20.5	523.2	0.0400
32	124	116	8	0.01	21.53	263.2	0.0560
33	116	96	20	0.02	21.54	1225.4	0.0247
34	96	85	11	0.01	23.4	618.0	0.0340
35	85	78	7	0.01	23.41	422.7	0.0450

Table 3. - continued -

Reach	start km	end km	Number of computational elements	Incremental Flow (m <sup>3</sup> /s)	Discharge <sup>1</sup> (m <sup>3</sup> /s)	Longitudinal Dispersion Constant (k)	Manning's roughness coefficient (n)
36	78	64	14	0.07	23.42	745.4	0.0320
37	64	63	1	0.09	23.58	589.4	0.0380
38	63	43	20	0.14	23.58	811.9	0.0358
39	43	23	20	0	23.72	714.0	0.0300
40	23	21	2	0	23.72	496.4	0.0405
41	21	13	8	0	23.82	506.2	0.0530
42	13	4	9	0	23.82	252.0	0.0680
43	4	1	3	0	23.82	19.4	0.0675
44	1	0	1	0	23.82	6.0	0.0676

<sup>1</sup> Refers to discharge at the beginning of the reach.

Table 4. Hydraulic data for the Assiniboine River during the July 2002 sampling period.

Reach	start km	end km	Number of computational elements	Incremental Flow (m <sup>3</sup> /s)	Discharge <sup>1</sup> (m <sup>3</sup> /s)	Longitudinal Dispersion Constant (k)	Manning's roughness coefficient (n)
1	287	286	1	0	10.19	1706.956	0.0252
2	286	282	4	0	10.19	998.887	0.0376
3	282	281	1	0	10.19	288.447	0.0525
4	281	277	4	0	10.19	370.048	0.0600
5	277	275	2	0	10.19	500.030	0.0503
6	275	274	1	0	10.19	873.187	0.0348
7	274	273	1	0	10.26	828.095	0.0375
8	273	272	1	0	10.26	379.715	0.0450
9	272	271	1	0	10.46	511.401	0.0450
10	271	270	1	0	10.79	393.128	0.0475
11	270	269	1	0	10.82	441.974	0.0524
12	269	268	1	0	10.82	565.310	0.0413
13	268	267	1	0	10.82	106.030	0.0900
14	267	266	1	0	10.82	500.679	0.0405
15	266	265	1	0	10.82	296.003	0.0533
16	265	264	1	0	10.82	273.616	0.0563
17	264	263	1	0	10.82	356.708	0.0414
18	263	262	1	0	10.82	302.549	0.0592
19	262	260	2	0	10.82	490.231	0.0398
20	260	252	8	0	10.82	427.389	0.0400
21	252	236	16	0	10.83	427.414	0.0440
22	236	226	10	0.23	10.83	334.477	0.0497
23	3	0	3	0	6.09	626.131	0.0390
24	226	207	19	0.49	17.2	648.770	0.0350
25	207	197	10	0.25	17.69	434.257	0.0350
26	197	193	4	0.27	17.98	1482.876	0.0250
27	193	179	14	0.18	18.19	3297.120	0.0150
28	179	172	7	0.18	18.39	623.569	0.0341
29	172	152	20	0.12	18.55	1326.701	0.0245
30	152	143	9	0.36	19.08	497.614	0.0400
31	143	124	19	0.36	19.42	513.089	0.0401
32	124	116	8	0.35	19.81	261.082	0.0555
33	116	96	20	0.22	20.12	1193.551	0.0247
34	96	85	11	0.06	20.43	594.735	0.0344
35	85	78	7	0.08	20.49	411.076	0.0450

Table 4. - continued -

Reach	start km	end km	Number of computational elements	Incremental Flow (m <sup>3</sup> /s)	Discharge <sup>1</sup> (m <sup>3</sup> /s)	Longitudinal Dispersion Constant (k)	Manning's roughness coefficient (n)
36	78	64	14	0.07	20.57	723.676	0.0321
37	64	63	1	0.09	20.72	564.781	0.0383
38	63	43	20	0.14	20.73	800.174	0.0355
39	43	23	20	0	20.86	650.740	0.0300
40	23	21	2	0	20.86	494.910	0.0405
41	21	13	8	0	20.86	508.343	0.0525
42	13	4	9	0	20.86	275.620	0.0676
43	4	1	3	0	20.86	460.452	0.0675
44	1	0	1	0	20.86	417.608	0.0676

<sup>1</sup> Refers to discharge at the beginning of the reach.



Table 5. Hydraulic data for the Assiniboine River during the August/September 2002 sampling period.

Reach	start km	end km	Number of computational elements	Incremental Flow (m <sup>3</sup> /s)	Discharge <sup>1</sup> (m <sup>3</sup> /s)	Longitudinal Dispersion Constant (k)	Manning's roughness coefficient (n)
1	287	286	1	0	8.29	1702.709	0.0250
2	286	282	4	0	8.29	1035.13	0.0375
3	282	281	1	0	8.29	280.9502	0.0530
4	281	277	4	0	8.29	403.4731	0.0600
5	277	275	2	0	8.29	534.7372	0.0500
6	275	274	1	0	8.29	846.4039	0.0345
7	274	273	1	0.02	8.31	806.4702	0.0375
8	273	272	1	0.02	8.32	364.818	0.0450
9	272	271	1	0.02	8.35	488.571	0.0450
10	271	270	1	0.02	8.49	378.689	0.0477
11	270	269	1	0.00	8.53	449.1826	0.0520
12	269	268	1	0.02	8.55	545.1053	0.0415
13	268	267	1	0.01	8.57	104.3113	0.0900
14	267	266	1	0.02	8.59	480.991	0.0405
15	266	265	1	0.01	8.6	279.7627	0.0535
16	265	264	1	0.01	8.62	264.8476	0.0565
17	264	263	1	0.01	8.63	339.7497	0.0415
18	263	262	1	0.02	8.65	293.2512	0.0592
19	262	260	2	0.09	8.69	409.2358	0.0400
20	260	252	8	0.27	8.77	408.7651	0.0400
21	252	236	16	0.07	9.01	420.0184	0.0440
22	236	226	10	0.42	9.12	317.7477	0.0498
23	3	0	3	0.00	1.42	560.1778	0.0390
24	226	207	19	0.81	10.96	722.8281	0.0350
25	207	197	10	0.42	11.77	412.4459	0.0350
26	197	193	4	0.44	12.26	1436.904	0.0250
27	193	179	14	0.29	12.61	3077.494	0.0150
28	179	172	7	0.30	12.92	580.8666	0.0340
29	172	152	20	0.44	13.2	1263.023	0.0245
30	152	143	9	0.59	14.07	483.8617	0.0400
31	143	124	19	0.60	14.62	486.4347	0.0400
32	124	116	8	0.58	15.26	253.0855	0.0560
33	116	96	20	0.33	15.78	1136.768	0.0247
34	96	85	11	0.06	16.21	573.4818	0.0340

Table 5. - continue -.

Reach	start km	end km	Number of computational elements	Incremental Flow (m <sup>3</sup> /s)	Discharge <sup>1</sup> (m <sup>3</sup> /s)	Longitudinal Dispersion Constant (k)	Manning's roughness coefficient (n)
35	85	78	7	0.08	16.28	393.9352	0.0450
36	78	64	14	0.07	16.36	704.1467	0.0320
37	64	63	1	0.09	16.51	549.0557	0.0380
38	63	43	20	0.14	16.52	789.6724	0.0358
39	43	23	20	0	16.65	526.6177	0.0300
40	23	21	2	0	16.65	487.2121	0.0405
41	21	13	8	0	16.65	500.6616	0.0530
42	13	4	9	0	16.65	114.8692	0.0680
43	4	1	3	0	16.65	12.93588	0.0675
44	1	0	1	0	16.65	6	0.0676

<sup>1</sup> Refers to discharge at the beginning of the reach.

Table 6. Discharge and concentrations of relevant parameters measured in effluents and tributaries to the Assiniboine River, June 2002.

Effluent or tributary	Date	Discharge m <sup>3</sup> /s	Temperature C	Specific Conductance mS/cm	TSS mg/L	Chlorophyll <i>a</i> µg/L	Phosphorus		
							Total mg/L P	Dissolved mg/L P	Organic mg/L P
Municipal Drainage Ditch	5-Jun-02	0.00362	19.2	3260	9	16	0.162	0.128	0.034
Willow Creek	5-Jun-02	0.0231	19.7	1340	11	6	0.148	0.122	0.026
Maple Leaf Effluent	5-Jun-02	0.03753	28.8	2290	14	170	17.6	17.4	0.200
Brandon Municipal Effluent	5-Jun-02	0.1628	17.6	1670	50	120	2.82	2.33	0.490
Little Souris River	6-Jun-02	0.0416	23.6	960	3	14	0.091	0.050	0.041
Five-mile Creek	7-Jun-02	0.0408	19.3	448	3	8	0.048	0.032	0.016
Souris River	7-Jun-02	2.83	19.5	1170	8	24	0.102	0.044	0.058
EpINETTE Creek	9-Jun-02	0.665	12.1	458	40	4	0.127	0.031	0.096
Cypress River	11-Jun-02	1.84	15.5	1010	210	14	0.292	0.095	0.197
Drain from south upstream of Site 13	13-Jun-02	0.100	14.8	1070	120	13	0.368	0.228	0.140

Table 6. - continued -

Effluent or tributary	Date	Nitrogen			
		Total mg/L	Dissolved Nitrate/Nitrite mg/L	Dissolved Ammonia mg/L	Organic mg/L
Municipal Drainage Ditch	5-Jun-02	297.0	227	75.8	0.0
Willow Creek	5-Jun-02	1.82	0.02	0.070	1.73
Maple Leaf Effluent	5-Jun-02	109.0	107	0.060	1.9
Brandon Municipal Effluent	5-Jun-02	10.70	0.20	5.37	5.13
Little Souris River	6-Jun-02	2.69	1.69	0.090	0.91
Five-mile Creek	7-Jun-02	0.22	0.02	0.001	0.20
Souris River	7-Jun-02	1.56	0.01	0.003	1.55
Epinette Creek	9-Jun-02	0.87	0.17	0.030	0.67
Cypress River	11-Jun-02	1.57	0.17	0.070	1.33
Drain from south upstream of Site 13	13-Jun-02	11.27	8.97	0.270	2.03

Table 7. Discharge and concentrations of relevant parameters measured in effluents and tributaries to the Assiniboine River, July 2002.

Effluent or tributary	Date	Discharge m <sup>3</sup> /s	Temperature C	Specific Conductance mS/cm	TSS mg/L	DO mg/L	CBOD mg/L	Chlorophyll <i>a</i> µg/L	Phosphorus		
									Total mg/L P	Dissolved mg/L P	Organic mg/L P
Municipal Drainage Ditch	16-Jul-02	0.0655	30.0	1.85	12	7.27	2.0	2	0.164	0.129	0.035
Willow Creek	16-Jul-02	0.202	29.0	1.47	22	7.04	2.0	8	0.348	0.265	0.083
Maple Leaf IWWTF Effluent	16-Jul-02	0.03281	32.0	2.72	3	4.90	2.0	8	18.4	18.4	0.000
Brandon Municipal WWTF effluent	16-Jul-02	0.33034	29.8	1.25	12	6.13	13.0	17	4.59	4.31	0.280
Little Souris River	17-Jul-02	0.0105	23.6	0.94	17	8.28	9.0	87	0.331	0.189	0.142
Five Mile Creek	18-Jul-02	0.0200	19.0	0.59	8	8.60	1.0	3	0.088	0.068	0.020
Souris River	18-Jul-02	6.09	24.2	1.28	42	7.42	4.5	18	0.321	0.191	0.130
EpINETTECreek	19-Jul-02	0.381	21.5	0.53	3	8.97	0.5	2	0.044	0.029	0.015
CypressRiver	21-Jul-02	0.09	27.0	0.73	10	8.64	0.5	6	0.087	0.053	0.034

Table 7. - continued –

Effluent or tributary	Date	Nitrogen			
		Total mg/L	Dissolved Nitrate/Nitrite mg/L N	Dissolved Ammonia mg/L N	Organic mg/L
Municipal Drainage Ditch	16-Jul-02	6.33	4	0.3	2.03
Willow Creek	16-Jul-02	2.02	0.02	0.009	1.991
Maple Leaf IWWTF Effluent	16-Jul-02	123	121	0.100	1.9
Brandon Municipal WWTF effluent	16-Jul-02	20.38	0.08	16.30	4
Little Souris River	17-Jul-02	2.35	0.35	0.012	1.988
Five Mile Creek	18-Jul-02	0.44	0.14	0.030	0.270
Souris River	18-Jul-02	2.17	0.02	0.005	2.146
EpinetteCreek	19-Jul-02	0.37	0.07	0.140	0.160
CypressRiver	21-Jul-02	0.82	0.02	0.007	0.793

Table 8. Discharge and concentrations of relevant parameters measured in effluents and tributaries to the Assiniboine River, August 2002.

Effluent or tributary	Date	Discharge m <sup>3</sup> /s	Temperature C	Specific Conductance mS/cm	TSS mg/L	DO mg/L	CBOD mg/L	Chlorophyll <i>a</i> µg/L	Phosphorus		
									Total mg/L P	Dissolved mg/L P	Organic mg/L P
Municipal Drainage Ditch	21-Aug-02	0.00482	15.5	3.33	6	4.30	5.0	3	0.328	0.311	0.017
Maple Leaf IWWTF Effluent	21-Aug-02	0.04325	28.6	2.69	2.5	7.13	2.0	3	16.2	16.0	0.200
Brandon Municipal WWTF Effluent	21-Aug-02	0.1183	18.7	1.33	31	6.94	8.0	6	4.99	4.51	0.480
Souris River	23-Aug-02	1.42	23.8	1.35	18	10.02	2.5	6	0.227	0.170	0.057
Epinette Creek	25-Aug-02	0.387	13.7	0.54	9	10.82	1.0	2	0.037	0.028	0.009
Cypress River	27-Aug-02	0.111	23.5	0.67	12	8.41	1.0	2	0.062	0.041	0.021

Table 8. - continued -

Effluent or tributary	Date	Nitrogen			
		Total mg/L	Dissolved Nitrate/Nitrite mg/L N	Dissolved Ammonia mg/L N	Organic mg/L
Municipal Drainage Ditch	21-Aug-02	289.0	213	71.9	4.1
Maple Leaf IWWTF Effluent	21-Aug-02	106.0	104	0.080	1.920
Brandon Municipal WWTF Effluent	21-Aug-02	21.8	0.13	18.00	3.7
Souris River	23-Aug-02	1.405	0.01	0.004	1.397
Epinette Creek	25-Aug-02	0.220	0.02	0.003	0.197
Cypress River	27-Aug-02	0.510	0.01	0.006	0.494

Table 9. Effluent quality for the Brandon Municipal Cell 5 outfall, open-water season 2002. Data provided by the City of Brandon.

	Sampling Date	24-hr Discharge (m <sup>3</sup> )	pH	TSS (mg/L)	5-day BOD (mg/L)	Ammonia-nitrogen		Total nitrogen		Total phosphorus	
						(mg/L)	(kg/d)	(mg/L)	(kg/d)	(mg/L)	(kg/d)
May	1-May-02	14,612	8.73	44	16	8.73	127.6	14.80	216.5	1.21	17.7
	8-May-02	13,920	8.18	67	14	6.52	90.8	14.90	207.4	1.25	17.4
	15-May-02	8,217	8.74	98	32	4.63	38.0	16.50	135.5	1.60	13.1
June	5-Jun-02	14,063	7.87	43	12	5.19	73.0	12.20	172.1	2.89	40.6
	12-Jun-02	15,895	7.83	48	14	9.38	149.1	13.00	207.1	3.10	49.3
	19-Jun-02	9,405	7.88	23	8	13.70	128.8	18.70	175.5	3.77	35.5
	26-Jun-02	9,160	7.95	14	12	16.10	147.5	19.00	173.9	4.08	37.4
July	3-Jul-02	15,071	8.06	43	19	17.50	263.7	21.50	324.3	4.54	68.4
	10-Jul-02	25,415	8.32	21	19	13.80	350.7	18.20	461.8	4.32	109.8
	17-Jul-02	9,234	7.74	23	12	15.50	143.1	16.90	155.8	4.76	44.0
	24-Jul-02	10,823	7.87	63	16	14.10	152.6	21.50	232.7	5.36	58.0
	31-Jul-02	11,717	8.35	68	15	9.99	117.1	17.40	204.2	4.54	53.2
August	7-Aug-02	12,360	7.86	35	19	11.40	140.9	16.50	203.7	4.79	59.2
	14-Aug-02	13,779	7.66	24	12	12.60	173.6	18.90	260.0	4.95	68.2
	21-Aug-02	10,225	7.60	30	28	17.60	180.0	28.80	294.1	4.96	50.7
	28-Aug-02	4,336	7.74	10	6	19.50	84.6	24.50	106.1	4.88	21.2
September	4-Sep-02	5,589	7.98	21	8	19.30	107.9	32.10	179.6	4.71	26.3
	11-Sep-02	18,072	8.22	14	6	17.80	321.7	21.50	389.3	4.37	79.0
	18-Sep-02	6,828	8.45	25	10	13.40	91.5	18.70	127.4	3.64	24.9
	25-Sep-02	11,115	8.60	16	10	11.10	123.4	14.90	165.8	2.86	31.8

Table 10. Effluent quality for the Maple Leaf IWWTF, open-water season 2002. Data provided by the City of Brandon.

	Sampling Date	24-hr Discharge (m <sup>3</sup> )	pH	TSS (mg/L)	5-day BOD (mg/L)	Ammonia-nitrogen		Total nitrogen		Total phosphorus	
						(mg/L)	(kg/d)	(mg/L)	(kg/d)	(mg/L)	(kg/d)
May	01-May-02	2,519	7.70	7	<6	0.13	0.3	85.7	215.9	14.10	35.5
	08-May-02	3,190	7.82	10	<6	0.14	0.4	119.0	379.6	13.40	42.7
	15-May-02	3,178	7.45	7	6	0.23	0.7	86.9	276.2	16.30	51.8
	22-May-02	2,274	7.70	17	10	0.21	0.5	94.7	215.3	12.90	29.3
	29-May-02	3,281	7.50	7	<6	0.19	0.6	97.5	319.9	18.00	59.1
June	5-Jun-02	3,243	7.51	6	<6	0.16	0.5	97.9	317.5	16.20	52.5
	12-Jun-02	3,156	7.77	6	<6	0.05	0.2	99.2	313.1	10.80	34.1
	19-Jun-02	3,217	7.63	5	<6	0.12	0.4	97.2	312.7	10.20	32.8
	26-Jun-02	3,160	7.58	5	<5	0.08	0.3	103.0	325.5	15.10	47.7
July	3-Jul-02	2,551	7.70	5	<6	0.18	0.5	112.0	285.7	11.50	29.3
	10-Jul-02	3,676	7.56	11	<6	3.58	13.2	102.0	375.0	17.60	64.7
	17-Jul-02	2,981	7.29	13	<6	0.12	0.4	107.0	319.0	20.00	59.6
	24-Jul-02	3,501	7.48	5	<6	0.14	0.5	106.0	371.1	17.20	60.2
	31-Jul-02	3,393	7.58	5	<6	0.12	0.4	105.0	356.3	14.10	47.8
August	7-Aug-02	3,114	7.54	5	<6	0.43	1.3	107.0	333.2	14.50	45.2
	14-Aug-02	3,192	7.71	6	<6	0.08	0.3	93.1	297.2	12.50	39.9
	21-Aug-02	3,737	7.53	9	<6	0.14	0.5	101.0	377.4	16.30	60.9
	28-Aug-02	3,497	7.32	8	<6	0.08	0.3	111.0	388.2	20.30	71.0
September	4-Sep-02	2,659	7.4	16	<6	0.53	1.4	111.0	295.1	16.40	43.6
	11-Sep-02	3,798	7.36	5	<6	0.14	0.5	96.9	368.0	21.00	79.8
	18-Sep-02	3,612	7.73	10	<6	0.08	0.3	101.0	364.8	15.30	55.3
	25-Sep-02	3,055	7.93	13	<6	0.05	0.2	106.0	323.8	11.40	34.8

Table 11. Concentrations of water quality variables measured at water quality monitoring site 2 during the monitoring periods in the open-water season of 2002.

Monitoring Period	Date	Time	Temperature C	Specific Conductance mS/cm	TSS mg/L	DO mg/L	CBOD mg/L	Chlorophyll <i>a</i> ug/L	Phosphorus		
									Total mg/L P	Dissolved mg/L P	Organic mg/L P
June 2002	5-Jun-02	10:00	17.1	0.98	35	8.57	1.0	16	0.081	0.034	0.047
July 2002	16-Jul-02	9:20	28.0	1.06	33	5.69	1.3	4	0.161	0.114	0.047
August 2002	22-Aug-02	10:40	19.5	0.99	29	8.35	2.0	11	0.107	0.057	0.050

Monitoring Period	Date	Nitrogen			
		Total mg/L	Dissolved Nitrate/Nitrite mg/L N	Dissolved Ammonia mg/L N	Organic mg/L
Jun-02	5-Jun-02	0.840	0.01	0.012	0.821
Jul-02	16-Jul-02	1.120	0.12	0.014	0.986
Aug-02	22-Aug-02	1.005	0.005	0.006	0.994

Table 12. Model settings and reaction coefficients (not reach-variable) for simulation of phytoplankton (as chlorophyll *a*) and nutrients in the Assiniboine River.

Parameter	Units	Value/Setting		
		June 2002	July 2002	August/September 2002
<b>Nitrification</b>				
Ammonia oxidation	mg oxygen/mg nitrogen	3.43	3.43	3.43
Nitrite oxidation	mg oxygen/mg nitrogen	1.14	1.14	1.14
Nitrification inhibition coefficient	-	10	10	10
<b>Algae (phytoplankton)</b>				
Rate of dissolved oxygen production per unit algal growth	(mg DO/L)/(mg algal biomass/L)	1.6	1.6	1.6
Rate of dissolved oxygen uptake per unit of algae respired	(mg DO/L)/(mg algal biomass/L)	2	2	2
Fraction of algal biomass that is nitrogen	(mg N/L)/(mg algal biomass/L)	0.085	0.085	0.085
Fraction of algal biomass that is phosphorus	(mg P/L)/(mg algal biomass/L)	0.014	0.014	0.014
Maximum specific algal growth rate	day-1	2.0	1.7	1.5
Local algal respiration rate	day-1	0.15	0.15	0.25
Nitrogen half-saturation coefficient	mg N/L	0.05	0.05	0.05
Phosphorus half-saturation coefficient	mg P/L	0.04	0.04	0.04
Algal preference factor for ammonia	-	0.6	0.5	0.6
Ratio of chlorophyll <i>a</i> to algal biomass	(ug chlorophyll <i>a</i> /L)/(mg algal biomass/L)	10	10	10
Linear algal self-shading coefficient	(1/m)/(µg chlorophyll <i>a</i> /L)	0.0088	0.0088	0.0088
Non-linear algal self-shading coefficient	(1/m)/(µg chlorophyll <i>a</i> /L)	0.054	0.054	0.054
<b>Light</b>				
Light Function	-	Option 1: Half Saturation	Option 1: Half Saturation	Option 1: Half Saturation
Light saturation coefficient	Langleys/min	0.029854	0.029854	1.029854
Light averaging from solar radiation	-	Option 2: Daily data	Option 2: Daily data	Option 2: Daily data

Table 12. - continued –

Parameter	Units	Value/Setting		
		June 2002	July 2002	August / September 2002
Light averaging factor	-	0.92	0.92	0.92
Number of daylight hours	hours	18	16	16
Total radiation	Langley	239.08 <sup>1</sup>	241.61 <sup>1</sup>	199.25 <sup>1</sup>
Light nutrient reactions	-	Option 1: Limiting nutrient	Option 1: Limiting nutrient	Option 1: Limiting nutrient

<sup>1</sup> Value derived from data provided by Environment Canada and corrected for fraction of photosynthetically reactive radiation using a factor of 0.44.

Table 13. Reach-variable rates for nitrogen and phosphorus processes, and phytoplankton dynamics, June 2002.

Model reach	Sampling Site	Temperature	Nitrogen parameters					Phosphorus parameters		
			Organic Nitrogen Mineralization	Organic nitrogen settling rate	Nitrification	Sediment source rate for ammonia	Oxidation of nitrite	Organic phosphorus mineralization	Organic phosphorus settling rate	Sediment source rate for dissolved phosphorus
		°C	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day
1	1	17.0	0.005	0	0.3	0	2	0.01	0.001	0
2		17.0	0.005	0	0.3	0	2	0.01	0.001	0
3		17.0	0.005	0	0.3	0	2	0.01	0.001	0
4		17.0	0.005	0	0.3	0	2	0.01	0.001	0
5		17.0	0.005	0	0.3	0	2	0.01	0.001	0
6	2	17.1	0.005	0	0.3	0	2	0.01	0.001	0
7		17.1	0.005	0	0.3	0	2	0.01	0.001	0
8	3	17.5	0.005	0	0.3	0	2	0.01	0.001	0
9		17.5	0.005	0	0.3	0	2	0.01	0.001	0
10		17.5	0.005	0	0.9	0	2	0.01	0.001	0
11		17.5	0.005	0	0.9	0	2	0.01	0.001	0
12		17.5	0.005	0	0.9	0	2	0.01	0.001	0
13	4	18.2	0.005	0	0.9	0	2	0.01	0.001	0
14		18.2	0.005	0	0.9	0	2	0.01	0.001	0
15		18.2	0.005	0	0.9	0	2	0.01	0.001	0
16		18.2	0.005	0	0.9	0	2	0.01	0.001	0
17	5	18.3	0.005	0	0.9	0	2	0.01	0.001	0
18		18.3	0.005	0	0.9	0	2	0.01	0.001	0
19		18.3	0.005	0	0.9	0	2	0.01	0.001	0
20	6	19.8	0.005	0	0.9	0	2	0.01	0.001	0
21	7	20.8	0.005	0	0.9	0	2	0.01	0.001	0
22	8	17.6	0.005	0	0.9	0	2	0.01	0.001	0
Souris: 23		19.5	0.005	0	0.9	0	2	0.01	0.001	0
24		17.6	0.005	0	0.9	0	2	0.01	0.001	0

Table 13. - continued -

Model reach	Sampling Site	Temperature	Nitrogen parameters					Phosphorus parameters			
			Organic Nitrogen Mineralization	Organic nitrogen settling rate	Nitrification	Sediment source rate for ammonia	Oxidation of nitrite	Organic phosphorus mineralization	Organic phosphorus settling rate	Sediment source rate for dissolved phosphorus	
		°C	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day	
25	9	17.7	0.005	0	0.9	0	2	0.01	0.001	0	
26		17.7	0.005	0	0.9	0	2	0.01	0.001	0	
27		17.7	0.005	0	0.9	0	2	0.01	0.001	0	
28		17.7	0.005	0	0.9	0	2	0.01	0.001	0	
29	10	16.5	0.005	0	0.3	0	2	0.01	0.001	0	
30		16.5	0.005	0	0.3	0	2	0.01	0.001	0	
31		16.5	0.005	0	0.3	0	2	0.01	0.001	0	
32		16.5	0.005	0	0.3	0	2	0.01	0.001	0	
33	11	14.3	0.005	0	0.3	0	2	0.01	0.001	0	
34		14.3	0.005	0	0.3	0	2	0.01	0.001	0	
35		14.3	0.005	0	0.3	0	2	0.01	0.001	0	
36		14.3	0.005	0	0.3	0	2	0.01	0.001	0	
37		14.3	0.005	0	0.3	0	2	0.01	0.001	0	
38	12	16.6	0.005	0	0.3	0	2	0.01	0.001	0	
39		16.6	0.005	0	0.3	0	2	0.01	0.001	0	
40		16.6	0.005	0	0.3	0	2	0.01	0.001	0	
41	13	17.3	0.005	0	0.3	0	2	0.01	0.001	0	
42		17.3	0.005	0	0.3	0	2	0.01	0.001	0	
43		17.3	0.005	0	0.3	0	2	0.01	0.001	0	
44	14	20.4	0.005	0	0.3	0	2	0.01	0.001	0	

Table 13. - continued –

Model reach	Sampling Site	Phytoplankton parameters		
		Chlorophyll <i>a</i> content of algae µg Chlorophyll <i>a</i> / mg algae	Phytoplankton settling rate m/day	Non-algal light extinction m <sup>-1</sup>
1	1	10	0	1
2		10	0	1
3		10	0	1
4		10	0	1
5		10	0	1
6	2	10	0	1
7		10	0	1
8	3	10	0	1
9		10	0	1
10		10	0	1
11		10	0	1
12		10	0	1
13	4	10	0	1
14		10	0	1
15		10	0	1
16		10	0	1
17	5	10	0.3	3
18		10	0.3	2
19		10	0.3	3
20	6	10	0.3	3
21	7	10	0.5	1
22	8	10	0.5	2
Souris:				
23		10	0	2
24		10	0.1	3

Table 13. - continued -

Model reach	Sampling Site	Phytoplankton parameters		
		Chlorophyll a content of algae $\mu\text{g Chlorophyll } a / \text{mg algae}$	Phytoplankton settling rate m/day	Non-algal light extinction $\text{m}^{-1}$
25	9	10	0	2
26		10	0	4
27		10	0	4
28		10	0	4
29	10	10	0	4
30		10	0	4
31		10	0	2
32		10	0	4
33	11	10	0	4
34		10	0	4
35		10	0	2
36		10	0	3
37		10	0	3
38	12	10	0	3
39		10	0	3
40		10	0	2
41	13	10	0	2
42		10	0	2
43		10	0	2
44	14	10	0.05	3

Table 14. Reach-variable rates for nitrogen and phosphorus processes, and phytoplankton dynamics, July 2002.

Model reach	Sampling Site	Temperature °C	Nitrogen parameters					Phosphorus parameters		
			Organic Nitrogen Mineralization day <sup>-1</sup>	Organic nitrogen settling rate day <sup>-1</sup>	Nitrification day <sup>-1</sup>	Sediment source rate for ammonia mg/m <sup>2</sup> /day	Oxidation of nitrite day <sup>-1</sup>	Organic phosphorus mineralization day <sup>-1</sup>	Organic phosphorus settling rate day <sup>-1</sup>	Sediment source rate for dissolved phosphorus mg/m <sup>2</sup> /day
1	1	28.5	0.005	0.01	0.3	0	2	0.002	0.005	0
2		28.5	0.005	0.01	0.3	0	2	0.002	0.005	0
3		28.5	0.005	0.01	0.3	0	2	0.002	0.005	0
4		28.5	0.005	0.01	0.3	0	2	0.002	0.005	0
5		28.5	0.005	0.01	0.3	0	2	0.002	0.005	0
6	2	28.0	0.005	0.01	0.3	0	2	0.002	0.005	0
7		28.0	0.005	0.01	0.3	0	2	0.002	0.005	0
8	3	28.2	0.005	0.01	0.3	0	2	0.002	0.005	0
9		28.2	0.005	0.01	0.3	0	2	0.002	0.005	0
10		28.2	0.005	0.01	0.9	0	2	0.002	0.005	0
11		28.2	0.005	0.01	0.9	0	2	0.002	0.005	0
12		28.2	0.005	0.01	0.9	0	2	0.002	0.005	0
13	4	28.7	0.005	0.01	0.9	0	2	0.002	0.005	0
14		28.7	0.005	0.01	0.9	0	2	0.002	0.005	0
15		28.7	0.005	0.01	0.9	0	2	0.002	0.005	0
16		28.7	0.005	0.01	0.9	0	2	0.002	0.005	0
17	5	29.3	0.005	0.01	0.9	0	2	0.002	0.005	0
18		29.3	0.005	0.01	0.9	0	2	0.002	0.005	0
19		29.3	0.005	0.01	0.9	0	2	0.002	0.005	0
20	6	25.9	0.005	0.01	0.9	0	2	0.002	0.005	0
21	7	25.4	0.005	0.01	0.9	0	2	0.002	0.005	0
22	8	25.6	0.005	0.01	0.9	0	2	0.002	0.005	0
Souris: 23		24.2	0.005	0.01	0.9	0	2	0.002	0.005	0
24		25.6	0.005	0.01	0.9	0	2	0.002	0.005	0

Table 14. - continued -

Model reach	Sampling Site	Temperature	Nitrogen parameters					Phosphorus parameters			
			Organic Nitrogen Mineralization	Organic nitrogen settling rate	Nitrification	Sediment source rate for ammonia	Oxidation of nitrite	Organic phosphorus mineralization	Organic phosphorus settling rate	Sediment source rate for dissolved phosphorus	
		°C	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day	
25	9	26.0	0.005	0.01	0.9	0	2	0.002	0.005	0	
26		26.0	0.005	0.01	0.9	0	2	0.002	0.005	0	
27		26.0	0.005	0.01	0.9	0	2	0.002	0.005	0	
28		26.0	0.005	0.01	0.9	0	2	0.002	0.005	0	
29	10	29.1	0.005	0.01	0.3	0	2	0.002	0.005	0	
30		29.1	0.005	0.01	0.3	0	2	0.002	0.005	0	
31		29.1	0.005	0.01	0.3	0	2	0.002	0.005	0	
32		29.1	0.005	0.01	0.3	0	2	0.002	0.005	0	
33	11	25.8	0.005	0.01	0.3	0	2	0.002	0.005	0	
34		25.8	0.005	0.01	0.3	0	2	0.002	0.005	0	
35		25.8	0.005	0.01	0.3	0	2	0.002	0.005	0	
36		25.8	0.005	0.01	0.3	0	2	0.002	0.005	0	
37		25.8	0.005	0.01	0.3	0	2	0.002	0.005	0	
38	12	24.6	0.005	0.01	0.3	0	2	0.002	0.005	0	
39		24.6	0.005	0.01	0.3	0	2	0.002	0.005	0	
40		24.6	0.005	0.01	0.3	0	2	0.002	0.005	0	
41	13	22.9	0.005	0.01	0.3	0	2	0.002	0.005	0	
42		22.9	0.005	0.01	0.3	0	2	0.002	0.005	0	
43		22.9	0.005	0.01	0.3	0	2	0.002	0.005	0	
44	14	24.1	0.005	0.01	0.3	0	2	0.002	0.005	0	

Table 14. - continued -

Model reach	Sampling Site	Phytoplankton parameters		
		Chlorophyll <i>a</i> content of algae µg Chlorophyll <i>a</i> / mg algae	Phytoplankton settling rate m/day	Non-algal light extinction m <sup>-1</sup>
1	1	10	0.3	2.5
2		10	0.3	2.5
3		10	0.3	2.5
4		10	0.3	2.5
5		10	0.3	2.5
6	2	10	0.3	2.7
7		10	0.3	2.7
8	3	10	0.3	2.6
9		10	0.3	2.6
10		10	0.3	2.6
11		10	0.3	2.6
12		10	0.3	2.6
13	4	10	0.3	2.4
14		10	0.3	2.4
15		10	0.3	2.4
16		10	0.3	2.4
17	5	10	0.3	2.3
18		10	0.3	2.3
19		10	0.3	2.3
20	6	10	0.3	2.4
21	7	10	0.3	2.5
22	8	10	0.3	2.6
Souris: 23		10	0.3	3.0
24		10	0.3	2.5

Table 14. - continued -

Model reach	Sampling Site	Phytoplankton parameters		
		Chlorophyll <i>a</i> content of algae µg Chlorophyll <i>a</i> / mg algae	Phytoplankton settling rate m/day	Non-algal light extinction m <sup>-1</sup>
25	9	10	0.3	2.6
26		10	0.3	2.6
27		10	0.3	2.6
28		10	0.3	2.6
29	10	10	0.3	2.9
30		10	0.3	2.9
31		10	0.3	2.9
32		10	0.3	2.9
33	11	10	0.3	3.2
34		10	0.3	3.2
35		10	0.3	3.2
36		10	0.3	3.2
37		10	0.3	3.2
38	12	10	0.3	4.3
39		10	0.3	4.3
40		10	0.3	4.3
41	13	10	0.3	2.3
42		10	0.3	2.3
43		10	0.3	2.3
44	14	10	0.3	2.3

Table 15. Reach-variable rates for nitrogen and phosphorus processes, and phytoplankton dynamics, August/September 2002.

Model reach	Sampling Site	Temperature °C	Nitrogen parameters					Phosphorus parameters		
			Organic Nitrogen Mineralization day <sup>-1</sup>	Organic nitrogen settling rate day <sup>-1</sup>	Nitrification day <sup>-1</sup>	Sediment source rate for ammonia mg/m <sup>2</sup> /day	Oxidation of nitrite day <sup>-1</sup>	Organic phosphorus mineralization day <sup>-1</sup>	Organic phosphorus settling rate day <sup>-1</sup>	Sediment source rate for dissolved phosphorus mg/m <sup>2</sup> /day
1	1	19.5	0.005	0.01	0.3	0	2	0.01	0.001	0
2		19.5	0.005	0.01	0.3	0	2	0.01	0.001	0
3		19.5	0.005	0.01	0.3	0	2	0.01	0.001	0
4		19.5	0.005	0.01	0.3	0	2	0.01	0.001	0
5		19.5	0.005	0.01	0.3	0	2	0.01	0.001	0
6	2	19.5	0.005	0.01	0.3	0	2	0.01	0.001	0
7		19.5	0.005	0.01	0.3	0	2	0.01	0.001	0
8	3	19.3	0.005	0.01	0.3	0	2	0.01	0.001	0
9		19.3	0.005	0.01	0.3	0	2	0.01	0.001	0
10		19.3	0.005	0.01	0.9	0	2	0.01	0.001	0
11		19.3	0.005	0.01	0.9	0	2	0.01	0.001	0
12		19.3	0.005	0.01	0.9	0	2	0.01	0.001	0
13	4	18.9	0.005	0.01	0.9	0	2	0.01	0.001	0
14		18.9	0.005	0.01	0.9	0	2	0.01	0.001	0
15		18.9	0.005	0.01	0.9	0	2	0.01	0.001	0
16		18.9	0.005	0.01	0.9	0	2	0.01	0.001	0
17	5	18.5	0.005	0.01	0.9	0	2	0.01	0.001	0
18		18.5	0.005	0.01	0.9	0	2	0.01	0.001	0
19		18.5	0.005	0.01	0.9	0	2	0.01	0.001	0
20	6	19.4	0.005	0.01	0.9	0	2	0.01	0.001	0
21	7	19.7	0.005	0.01	0.9	0	2	0.01	0.001	0
22	8	21.1	0.005	0.01	0.9	0	2	0.01	0.001	0
Souris: 23		21.1	0.005	0.01	0.9	0	2	0.01	0.001	0
24		21.1	0.005	0.01	0.9	0	2	0.01	0.001	0

Table 15. - continued -

Model reach	Sampling Site	Temperature	Nitrogen parameters					Phosphorus parameters			
			Organic Nitrogen Mineralization	Organic nitrogen settling rate	Nitrification	Sediment source rate for ammonia	Oxidation of nitrite	Organic phosphorus mineralization	Organic phosphorus settling rate	Sediment source rate for dissolved phosphorus	
		°C	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day	day <sup>-1</sup>	day <sup>-1</sup>	day <sup>-1</sup>	mg/m <sup>2</sup> /day	
25	9	22.1	0.005	0.01	0.9	0	2	0.01	0.001	0	
26		22.1	0.005	0.01	0.9	0	2	0.01	0.001	0	
27		22.1	0.005	0.01	0.9	0	2	0.01	0.001	0	
28		22.1	0.005	0.01	0.9	0	2	0.01	0.001	0	
29	10	22.5	0.005	0.01	0.3	0	2	0.01	0.001	0	
30		22.5	0.005	0.01	0.3	0	2	0.01	0.001	0	
31		22.5	0.005	0.01	0.3	0	2	0.01	0.001	0	
32		22.5	0.005	0.01	0.3	0	2	0.01	0.001	0	
33	11	23.1	0.005	0.01	0.3	0	2	0.01	0.001	0	
34		23.1	0.005	0.01	0.3	0	2	0.01	0.001	0	
35		23.1	0.005	0.01	0.3	0	2	0.01	0.001	0	
36		23.1	0.005	0.01	0.3	0	2	0.01	0.001	0	
37		23.1	0.005	0.01	0.3	0	2	0.01	0.001	0	
38	12	24.7	0.005	0.01	0.3	0	2	0.01	0.001	0	
39		24.7	0.005	0.01	0.3	0	2	0.01	0.001	0	
40		24.7	0.005	0.01	0.3	0	2	0.01	0.001	0	
41	13	22.0	0.005	0.01	0.3	0	2	0.01	0.001	0	
42		22.0	0.005	0.01	0.3	0	2	0.01	0.001	0	
43		22.0	0.005	0.01	0.3	0	2	0.01	0.001	0	
44	14	19.8	0.005	0.01	0.3	0	2	0.01	0.001	0	

Table 15. - continued -

Model reach	Sampling Site	Phytoplankton parameters		
		Chlorophyll <i>a</i> content of algae µg Chlorophyll <i>a</i> / mg algae	Phytoplankton settling rate m/day	Non-algal light extinction m <sup>-1</sup>
1	1	10	0	2.6
2		10	0	2.6
3		10	0	2.6
4		10	0	2.6
5		10	0	2.6
6	2	10	0	2.9
7		10	0	2.9
8	3	10	0	3.1
9		10	0	3.1
10		10	0	3.1
11		10	0	3.1
12		10	0	3.1
13	4	10	0	3
14		10	0	3
15		10	0	3
16		10	0	3
17	5	10	0.3	2.9
18		10	0.3	2.9
19		10	0.3	2.9
20	6	10	0.3	2.6
21	7	10	0.5	2.1
22	8	10	0.5	2.1
Souris: 23		10	0	2.2
24		10	0.1	2.1

Table 15. - continued -

Model reach	Sampling Site	Phytoplankton parameters		
		Chlorophyll <i>a</i> content of algae µg Chlorophyll <i>a</i> / mg algae	Phytoplankton settling rate m/day	Non-algal light extinction m <sup>-1</sup>
25	9	10	0	2.4
26		10	0	2.4
27		10	0	2.4
28		10	0	2.4
29	10	10	0	2.9
30		10	0	2.9
31		10	0	2.9
32		10	0	2.9
33	11	10	0	3.8
34		10	0	3.8
35		10	0	3.8
36		10	0	3.8
37		10	0	3.8
38	12	10	0	5
39		10	0	5
40		10	0	5
41	13	10	0	5.4
42		10	0	5.4
43		10	0	5.4
44	14	10	0.05	2.2



Table 16. Temperature correction factors for rate processes and kinetics.

Parameter	Temperature Correction Factor
<b>Nitrogen</b>	
Organic nitrogen settling	1.024
Organic nitrogen mineralization	1.047
Ammonia oxidation	1.083
Nitrite oxidation	1.047
<b>Phosphorus</b>	
Organic phosphorus settling	1.024
Organic phosphorus mineralization	1.047
<b>Algae (phytoplankton)</b>	
Algal growth	1.047
Algal respiration	1.047
Algal settling	1.024



Table 17. Comparison of in-stream loads of total phosphorus using measured concentrations and simulated concentrations (as a mass-balance): June 2002.

Sampling Site	Distance downstream (km)	Measured Concentrations (kg/day)				Simulated Concentrations (kg/day)	Difference (kg/day)			
		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average
1	0	60.6	-	58.9	59.7	67.3	6.7	-	8.4	7.6
2	12.8	68.2	66.5	70.7	68.4	67.3	-0.9	0.8	-3.4	-1.1
3	14.38	71.5	65.5	67.2	68.1	68.1	-3.4	2.6	0.9	0.0
4	19.98	178.0	137.0	132.6	149.2	169.1	-8.9	32.1	36.5	19.9
5	23.81	158.8	140.6	135.2	144.8	163.3	4.5	22.7	28.1	18.5
6	27.82	136.0	130.3	125.6	130.6	170.0	34.0	39.7	44.4	39.4
7	37.19	129.2	124.1	126.1	126.5	161.5	32.3	37.4	35.4	35.0
8	51.26	135.0	-	131.9	133.5	164.9	29.9	-	33.0	31.4
9	80.66	129.8	-	131.1	130.5	172.2	42.4	-	41.1	41.7
10	115.31	156.3	-	156.3	156.3	170.2	13.9	-	13.9	13.9
11	184.96	338.7	-	169.4	254.0	186.1	-152.6	-	16.7	-67.9
12	224.71	315.8	-	336.2	326.0	224.1	-91.7	-	-112.1	-101.9
13	266.05	286.1	-	286.1	286.1	226.4	-59.7	-	-59.7	-59.7
14	287	144.1	-	142.0	143.0	226.4	82.3	-	84.4	83.4

Table 18. Comparison of in-stream loads of total nitrogen using measured concentrations and simulated concentrations (as a mass-balance): June 2002.

Sampling Site	Distance downstream (km)	Measured Concentrations (kg/day)				Simulated Concentrations (kg/day)	Difference (kg/day)			
		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average
1	0	681.6	-	605.9	643.78	706.9	25.3	-	101.0	63.1
2	12.8	677.4	677.4	765.8	706.89	715.3	37.9	37.9	-50.5	8.4
3	14.38	1523.4	689.3	697.9	970.19	808.5	-714.9	119.2	110.6	-161.7
4	19.98	1788.7	1308.2	1121.3	1406.07	1317.1	-471.6	8.9	195.8	-89.0
5	23.81	1333.6	1242.9	1270.1	1282.18	1315.4	-18.2	72.5	45.3	33.2
6	27.82	1256.0	1171.0	1152.1	1193.03	1312.6	56.6	141.6	160.5	119.6
7	37.19	1200.9	1200.9	1281.6	1227.80	1322.0	121.1	121.1	40.4	94.2
8	51.26	1144.1	-	1144.1	1144.13	1329.7	185.6	-	185.6	185.6
9	80.66	1198.7	-	1198.7	1198.68	1496.7	298.0	-	298.0	298.0
10	115.31	1408.2	-	1268.9	1338.52	1485.5	77.3	-	216.6	147.0
11	184.96	1786.6	-	1879.7	1833.14	1544.7	-241.9	-	-335.0	-288.4
12	224.71	2047.5	-	2047.5	2047.50	1792.8	-254.7	-	-254.7	-254.7
13	266.05	1667.0	-	1461.2	1564.12	1893.4	226.4	-	432.2	329.3
14	287	1914.0	-	1955.1	1934.57	1893.4	-20.6	-	-61.7	-41.2

Table 19. Comparison of in-stream loads of total phosphorus using measured concentrations and simulated concentrations (as a mass-balance): July 2002.

Sampling Site	Distance downstream (km)	Measured Concentrations (kg/day)				Simulated Concentrations (kg/day)	Difference (kg/day)			
		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average
1	0	132.9	-	135.6	134.3	140.9	7.9	-	5.3	6.6
2	12.8	142.6	142.6	140.0	141.7	140.9	-1.8	-1.8	0.9	-0.9
3	14.38	140.9	144.5	148.9	144.8	141.8	0.9	-2.7	-7.1	-3.0
4	19.98	270.2	277.6	310.4	286.1	336.6	66.4	58.9	26.2	50.5
5	23.81	268.3	270.2	269.2	269.2	336.6	68.2	66.4	67.3	67.3
6	27.82	254.3	262.7	248.7	255.2	336.6	82.3	73.9	87.9	81.3
7	37.19	276.0	267.6	291.9	278.5	336.9	60.8	69.2	44.9	58.3
8	51.26	262.9	-	256.4	259.7	336.9	73.9	-	80.5	77.2
9	80.66	447.8	-	446.3	447.1	504.4	56.6	-	58.1	57.3
10	115.31	411.9	-	403.9	407.9	496.8	84.9	-	93.0	88.9
11	184.96	385.5	-	406.4	396.0	505.9	120.4	-	99.4	109.9
12	224.71	372.5	-	367.2	369.9	501.5	129.0	-	134.3	131.6
13	266.05	401.9	-	383.9	392.9	504.7	102.7	-	120.8	111.7
14	287	380.3	-	385.7	383.0	504.7	124.4	-	119.0	121.7

Table 20. Comparison of in-stream loads of total nitrogen using measured concentrations and simulated concentrations (as a mass-balance): July 2002.

Sampling Site	Distance downstream (km)	Measured Concentrations (kg/day)				Simulated Concentrations (kg/day)	Difference (kg/day)			
		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average
1	0	880.4	-	792.4	836.4	986.1	105.7	-	193.7	149.7
2	12.8	986.1	986.1	986.1	986.1	986.1	0.0	0.0	0.0	0.0
3	14.38	1010.6	1010.6	975.1	998.7	1028.3	17.7	17.7	53.2	29.6
4	19.98	1692.1	1607.9	1654.7	1651.6	2000.6	308.5	392.6	345.9	349.0
5	23.81	1692.1	1598.6	1673.4	1654.7	2000.6	308.5	402.0	327.2	345.9
6	27.82	1486.4	1542.5	1514.5	1514.5	2000.6	514.2	458.1	486.1	486.1
7	37.19	1525.2	1553.3	1478.4	1519.0	2002.4	477.2	449.1	524.0	483.4
8	51.26	1459.7	-	1403.6	1431.6	1993.1	533.4	-	589.5	561.4
9	80.66	1666.0	-	2583.0	2124.5	3148.5	1482.6	-	565.5	1024.0
10	115.31	2291.9	-	2275.9	2283.9	3141.3	849.4	-	865.5	857.5
11	184.96	2477.1	-	2110.7	2293.9	3157.4	680.3	-	1046.6	863.5
12	224.71	2185.1	-	1979.1	2082.1	3170.2	985.1	-	1191.1	1088.1
13	266.05	2171.8	-	2180.8	2176.3	3172.1	1000.3	-	991.3	995.8
14	287	2216.8	-	2198.8	2207.8	3172.1	955.2	-	973.2	964.2

Table 21. Comparison of in-stream loads of total phosphorus using measured concentrations and simulated concentrations (as a mass-balance): August/September 2002.

Sampling Site	Distance downstream (km)	Measured Concentrations (kg/day)				Simulated Concentrations (kg/day)	Difference (kg/day)			
		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average
1	0	93.8	-	94.5	94.2	78.8	-15.0	-	-15.8	-15.4
2	12.8	71.6	71.6	86.0	76.4	78.8	7.2	7.2	-7.2	2.4
3	14.38	84.1	71.9	71.2	75.7	79.1	-5.0	7.2	7.9	3.4
4	19.98	184.4	156.2	170.3	170.3	192.5	8.1	36.3	22.2	22.2
5	23.81	187.9	178.2	169.3	178.5	186.4	-1.5	8.2	17.2	8.0
6	27.82	177.3	176.6	178.8	177.6	189.4	12.1	12.6	10.6	11.9
7	37.19	166.0	162.9	164.4	164.4	187.0	21.0	50.7	22.6	22.6
8	51.26	124.5	-	126.1	125.3	189.1	64.6	-	63.0	63.8
9	80.66	136.3	-	135.3	135.8	213.6	77.3	-	78.3	77.8
10	115.31	174.5	-	171.1	172.8	216.7	42.2	-	45.6	43.9
11	184.96	198.9	-	223.6	211.3	219.5	20.6	-	-4.1	8.2
12	224.71	238.4	-	215.5	226.9	214.1	-24.3	-	-1.4	-12.8
13	266.05	241.7	-	214.3	228.0	215.8	-25.9	-	1.4	-12.2
14	287	172.6	-	178.4	175.5	215.8	43.2	-	37.4	40.3

Table 22. Comparison of in-stream loads of total nitrogen using measured concentrations and simulated concentrations (as a mass-balance): August/September 2002.

Sampling Site	Distance downstream (km)	Measured Concentrations (kg/day)				Simulated Concentrations (kg/day)	Difference (kg/day)			
		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average		Measured: Left channel	Measured: Centre channel	Measured: Right channel	Average
1	0	1149.6	-	1149.6	1149.6	716.3	-433.3	-	-433.3	-433.3
2	12.8	719.8	719.8	719.8	719.8	737.7	17.9	17.9	17.9	17.9
3	14.38	704.5	927.3	722.4	784.7	848.2	143.8	-79.1	125.8	63.5
4	19.98	1495.7	1147.7	940.4	1194.6	1473.5	-22.2	325.8	533.1	278.9
5	23.81	1498.7	1461.4	1342.1	1434.1	1468.9	-29.8	7.5	126.8	34.8
6	27.82	1371.5	1439.7	1348.8	1386.6	1470.0	98.5	30.3	121.2	83.3
7	37.19	1044.3	1052.1	943.0	1013.1	1472.9	428.6	420.8	529.9	459.8
8	51.26	748.6	-	843.1	795.8	1473.5	724.9	-	630.4	677.7
9	80.66	833.9	-	732.2	783.0	1637.3	803.4	-	905.1	854.2
10	115.31	918.1	-	918.1	918.1	1642.3	724.2	-	724.2	724.2
11	184.96	1104.5	-	1104.5	1104.5	1646.4	542.0	-	542.0	542.0
12	224.71	1313.1	-	1170.4	1241.8	1655.7	342.6	-	485.3	413.9
13	266.05	877.5	-	1445.8	1161.6	1654.3	776.8	-	208.6	492.7
14	287	1589.6	-	1445.8	1517.7	1654.3	64.7	-	208.6	136.7

Table 23. Summary of total nitrogen and phosphorus loads measured in discharges from the Brandon Municipal WWTF, Maple Leaf IWWTF, and the municipal drainage ditch that receives discharge from the Simplot Fertilizer Facility and the Brandon Thermal Generating Station Ash Lagoon during the June 2002 monitoring period.

Source	Date	Calculated Load (kg/day)	
		Total Nitrogen	Total Phosphorus
Simplot/Ash Lagoon Drainage Ditch	3-Jun-02	200.5	0.09
Brandon Municipal WWTF	3-Jun-03	127.1	33.11
Maple Leaf IWWTF	3-Jun-03	308.3	31.41
<b>Sub-Total</b>	<b>3-Jun-03</b>	<b>635.9</b>	<b>64.61</b>
Simplot/Ash Lagoon Drainage Ditch	4-Jun-02	119.5	0.06
Brandon Municipal WWTF	4-Jun-02	157.7	40.87
Maple Leaf IWWTF	4-Jun-02	355.6	49.47
<b>Sub-Total</b>	<b>4-Jun-02</b>	<b>632.8</b>	<b>90.4</b>
Simplot/Ash Lagoon Drainage Ditch	5-Jun-02	92.9	0.05
Brandon Municipal WWTF	5-Jun-02	150.5	39.66
Maple Leaf IWWTF	5-Jun-02	353.5	57.08
<b>Sub-Total</b>	<b>5-Jun-02</b>	<b>596.9</b>	<b>96.79</b>
Simplot/Ash Lagoon Drainage Ditch	6-Jun-02	601.7	0.80
Brandon Municipal WWTF	6-Jun-02	123.2	39.42
Maple Leaf IWWTF	6-Jun-02	346.8	55.36
<b>Sub-Total</b>	<b>6-Jun-02</b>	<b>1071.7</b>	<b>95.58</b>

Table 24. Summary of total nitrogen and phosphorus loads measured in discharges from the Brandon Municipal WWTF, Maple Leaf IWWTF, and the municipal drainage ditch that receives discharge from the Simplot Fertilizer Facility and the Brandon Thermal Generating Station Ash Lagoon during the July 2002 monitoring period.

Source	Date	Calculated Load (kg/day)	
		Total Nitrogen	Total Phosphorus
Simplot/Ash Lagoon Drainage Ditch	15-Jul-02	39.06	0.79
Brandon Municipal WWTF	15-Jul-02	521.93	126.93
Maple Leaf IWWTF	15-Jul-02	398.72	57.84
<b>Sub-Total</b>	<b>15-Jul-02</b>	<b>959.71</b>	<b>185.56</b>
Simplot/Ash Lagoon Drainage Ditch	16-Jul-02	35.81	0.93
Brandon Municipal WWTF	16-Jul-02	581.67	131
Maple Leaf IWWTF	16-Jul-02	348.17	51.6
<b>Sub-Total</b>	<b>16-Jul-02</b>	<b>965.65</b>	<b>183.53</b>
Simplot/Ash Lagoon Drainage Ditch	17-Jul-02	22.11	0.67
Brandon Municipal WWTF	17-Jul-02	178.68	42.01
Maple Leaf IWWTF	17-Jul-02	334.17	56.34
<b>Sub-Total</b>	<b>17-Jul-02</b>	<b>534.96</b>	<b>99.02</b>

Table 25. Summary of total nitrogen and phosphorus loads measured in discharges from the Brandon Municipal WWTF, Maple Leaf IWWTF, and the municipal drainage ditch that receives discharge from the Simplot Fertilizer Facility and the Brandon Thermal Generating Station Ash Lagoon during the August/September 2002 monitoring period.

Source	Date	Calculated Load (kg/day)	
		Total Nitrogen	Total Phosphorus
Simplot/Ash Lagoon Drainage Ditch	20-Aug-02	25.64	0.06
Brandon Municipal WWTF	20-Aug-02	277.18	65.7
Maple Leaf IWWTF	20-Aug-02	380.32	38.03
<b>Sub-Total</b>	<b>20-Aug-02</b>	<b>683.14</b>	<b>103.79</b>
Simplot/Ash Lagoon Drainage Ditch	21-Aug-02	120.28	0.14
Brandon Municipal WWTF	21-Aug-02	223.21	51.02
Maple Leaf IWWTF	21-Aug-02	396.12	60.54
<b>Sub-Total</b>	<b>21-Aug-02</b>	<b>739.61</b>	<b>111.70</b>
Simplot/Ash Lagoon Drainage Ditch	22-Aug-02	60.72	0.07
Brandon Municipal WWTF	22-Aug-02	173.33	43.04
Maple Leaf IWWTF	22-Aug-02	398.34	70.27
<b>Sub-Total</b>	<b>22-Aug-02</b>	<b>632.39</b>	<b>113.38</b>



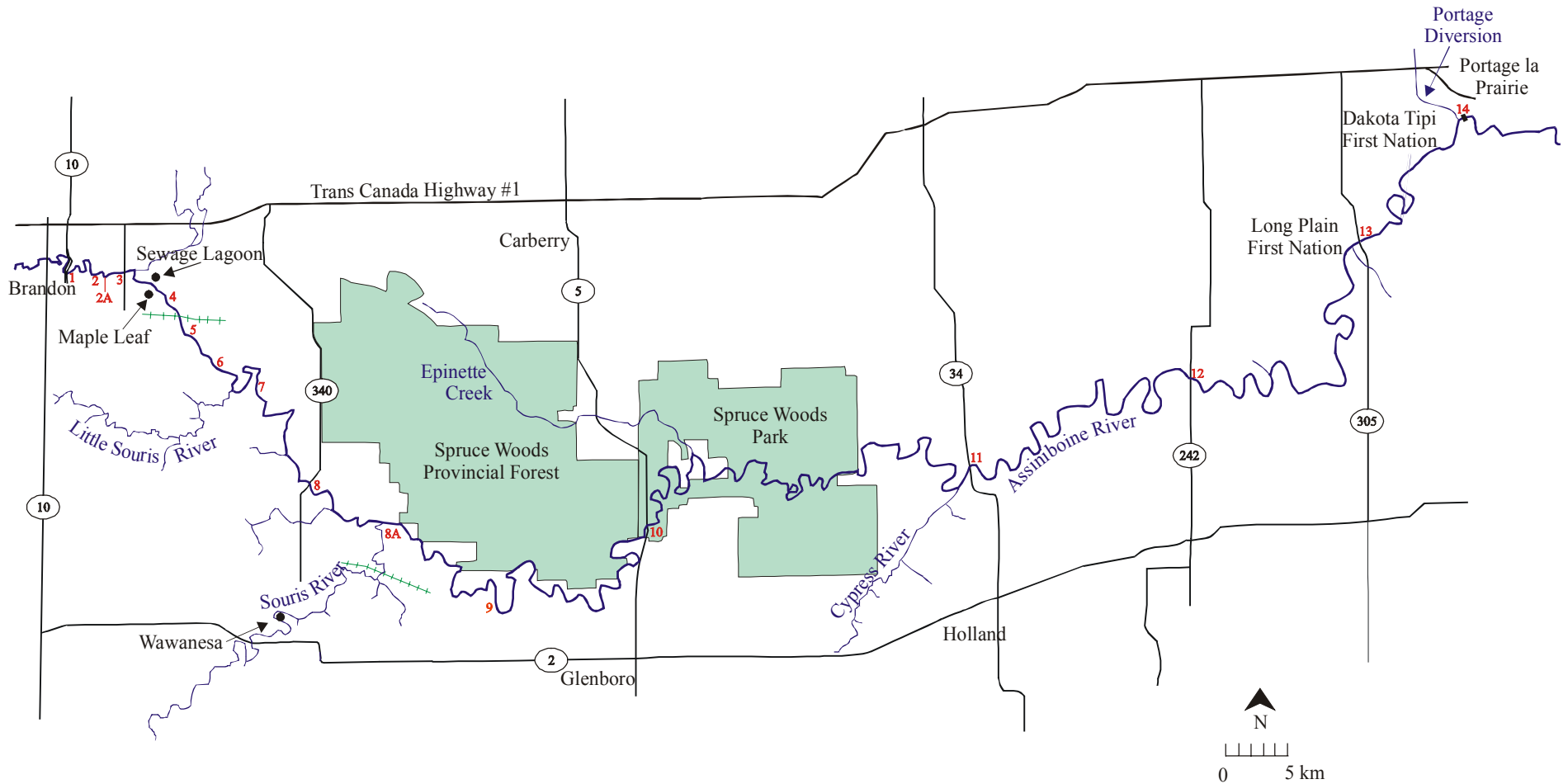


Figure 1. Study area of the Assiniboine River Monitoring Study (Brandon to Portage la Prairie), with sampling site locations.

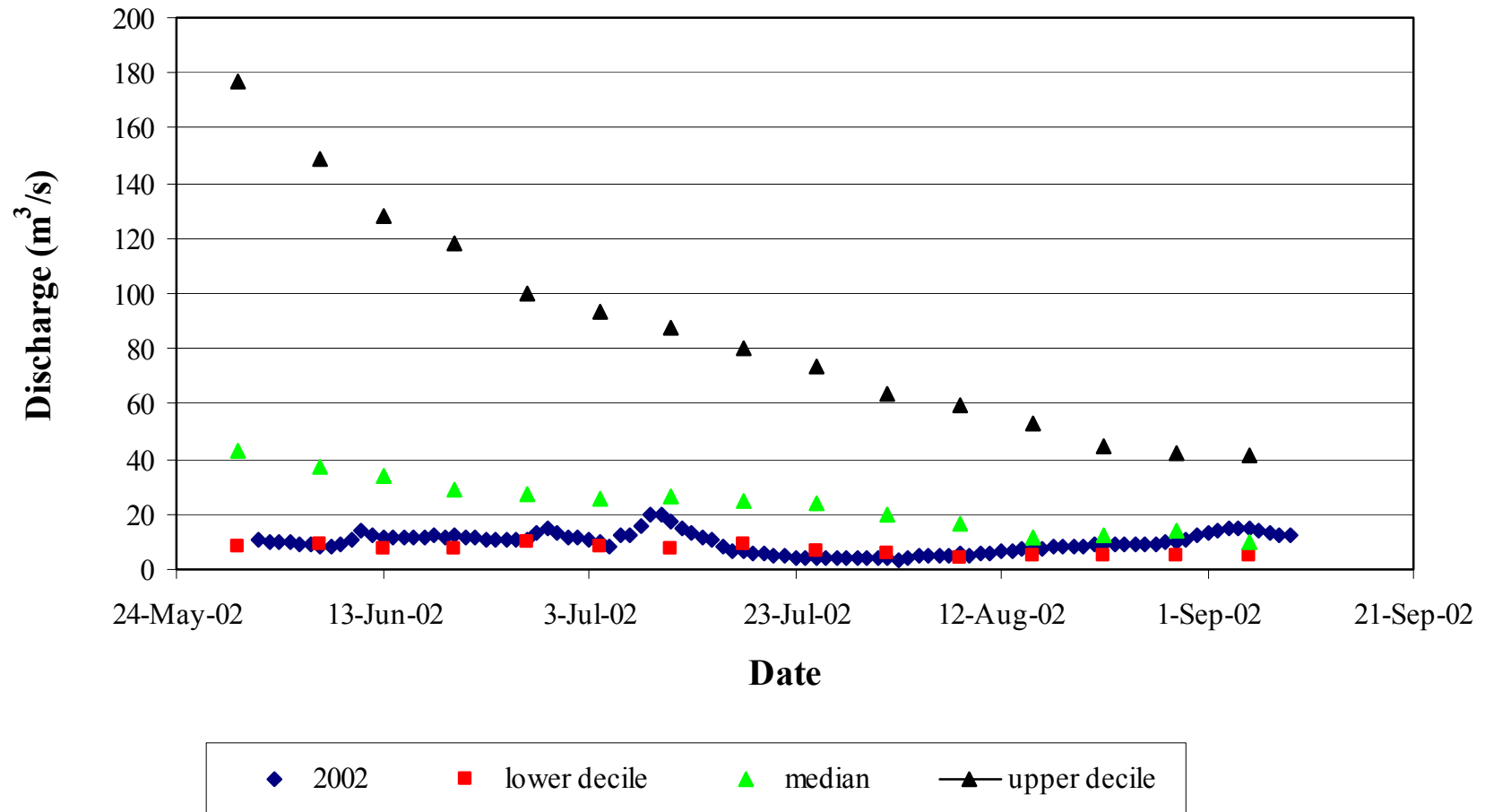


Figure 2. Assiniboine River discharge measured at Brandon for the months of June through August, 2002. Weekly lower decile, median, and upper decile flows are included for comparison.

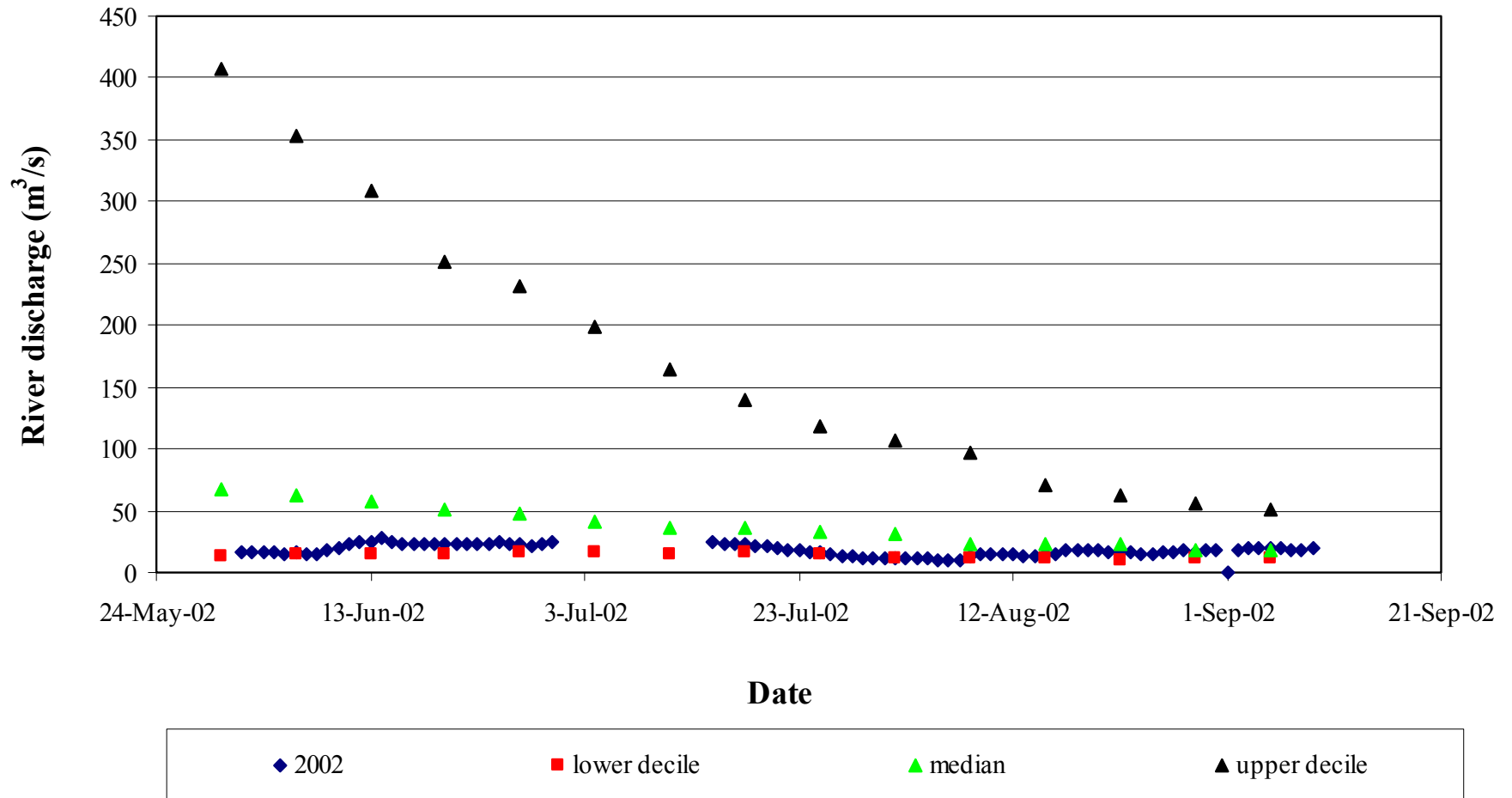


Figure 3. Assiniboine River discharge measured at Holland for the months of June through August, 2002. Weekly lower decile, median, and upper decile flows are included for comparison.

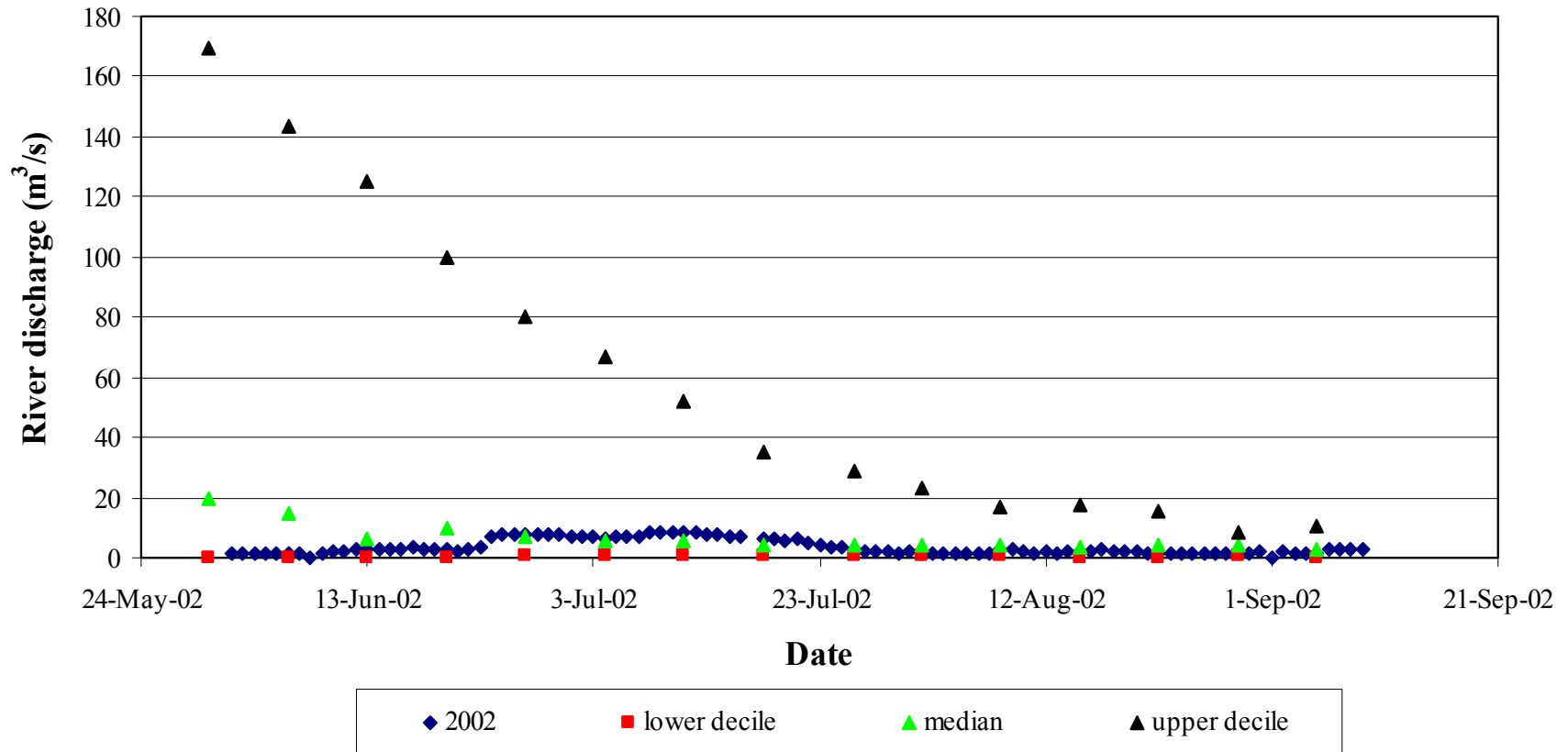


Figure 4. Souris River discharge measured at Brandon for the months of June through August, 2002. Weekly lower decile, median, and upper decile flows are included for comparison.

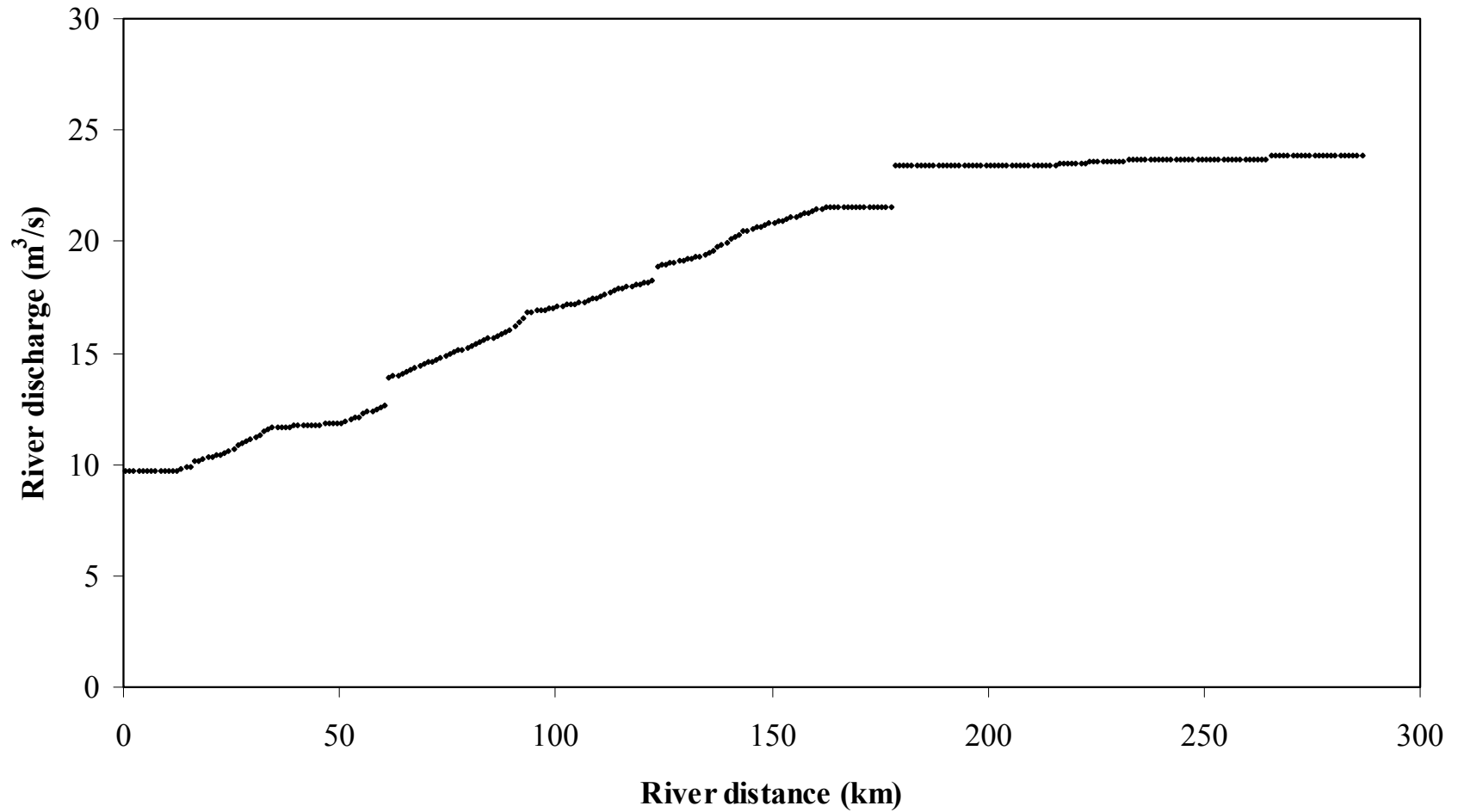


Figure 5. Simulated Assiniboine River discharge for the June 2002 monitoring period.

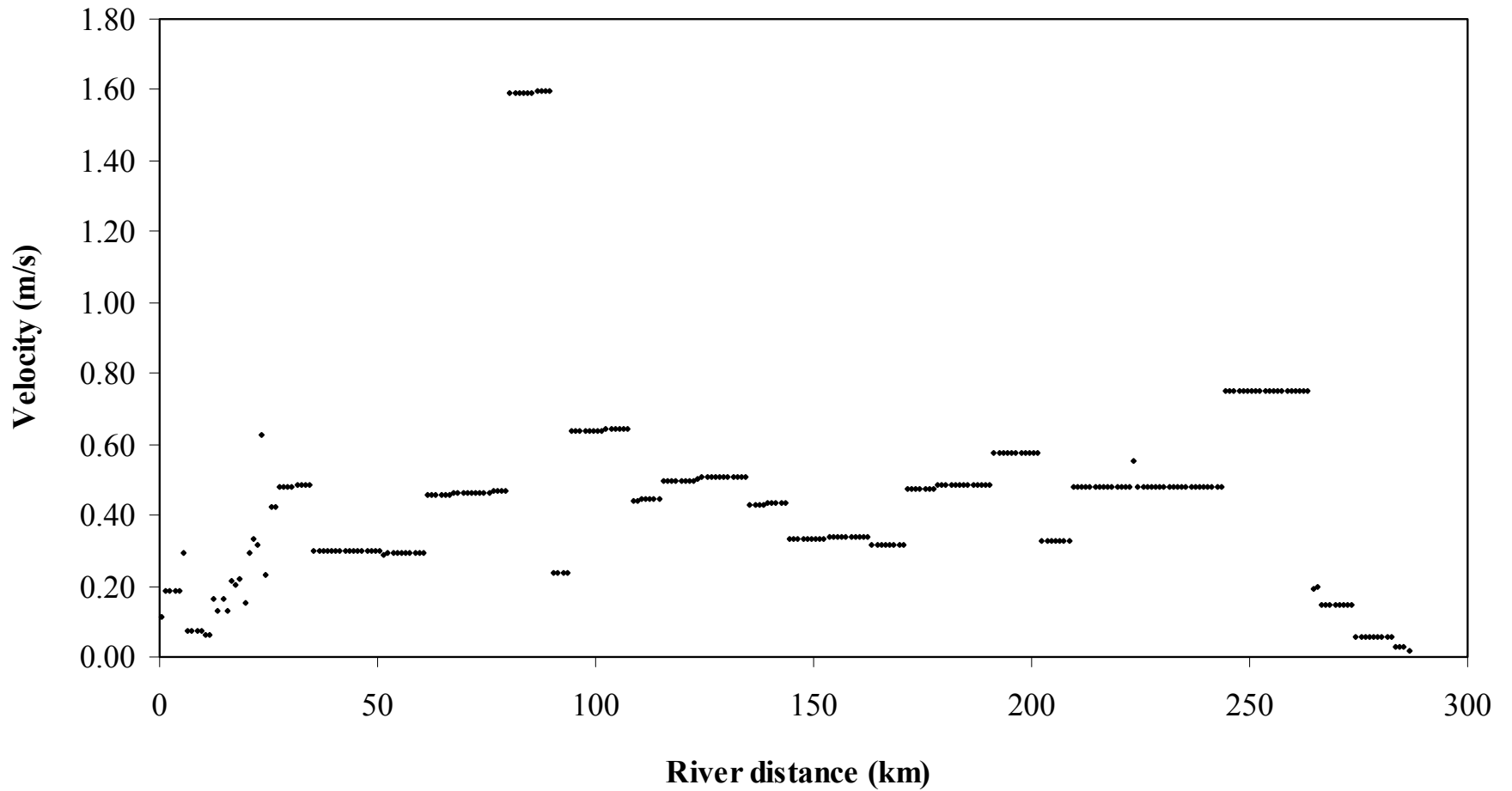


Figure 6. Simulated Assiniboine River velocities for the June 2002 monitoring period.

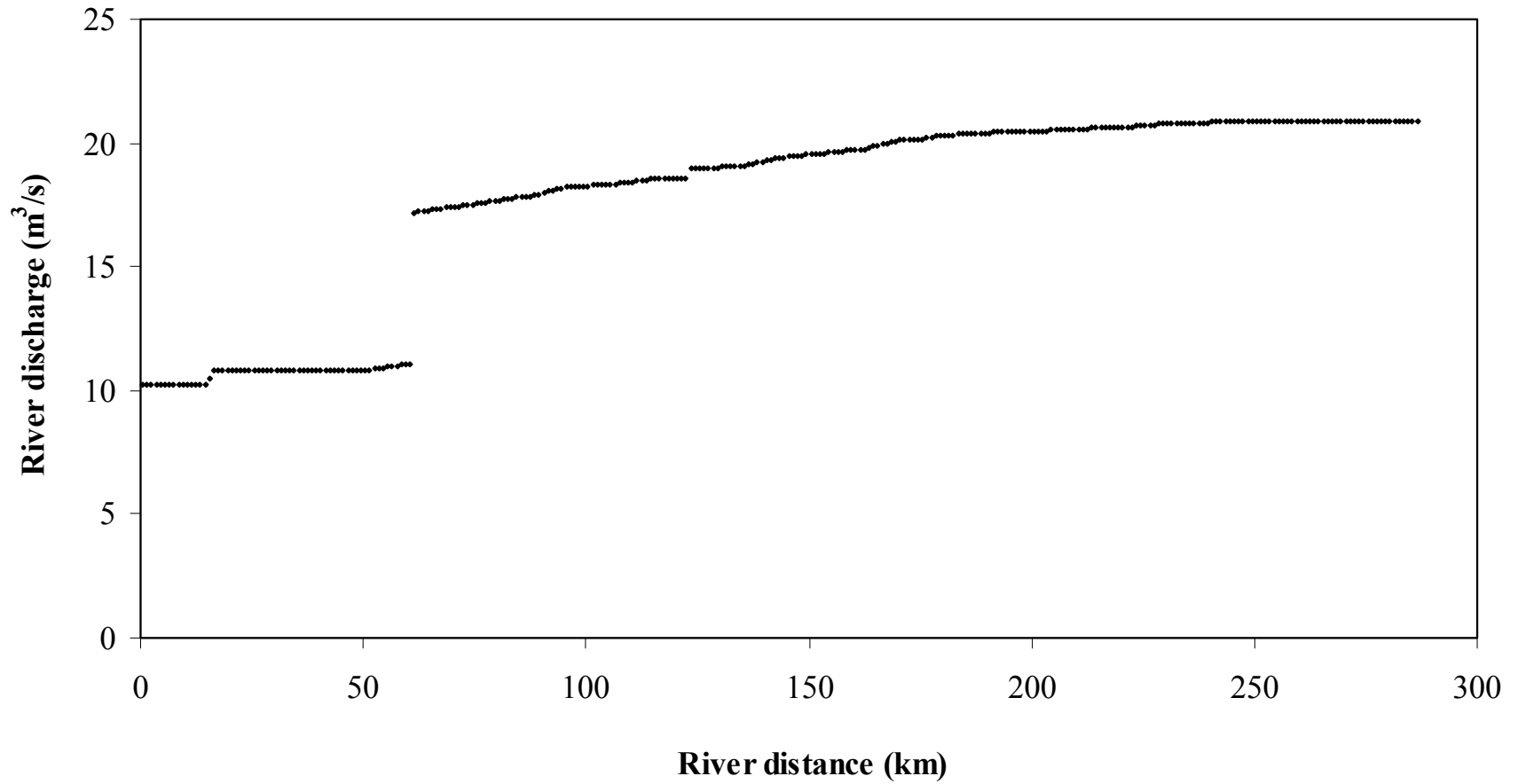


Figure 7. Simulated Assiniboine River discharge for the July 2002 monitoring period.

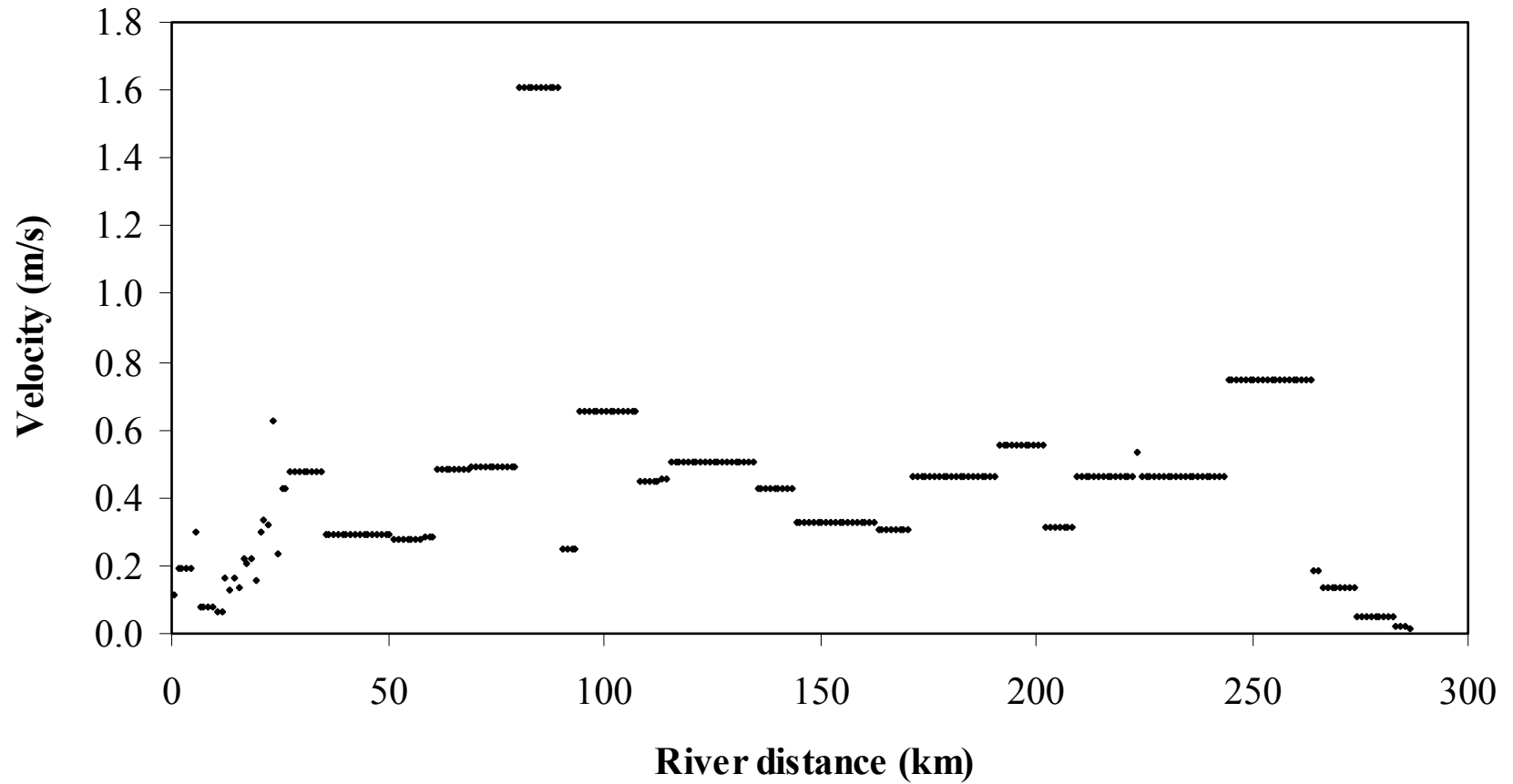


Figure 8. Simulated Assiniboine River velocities for the July 2002 monitoring period.

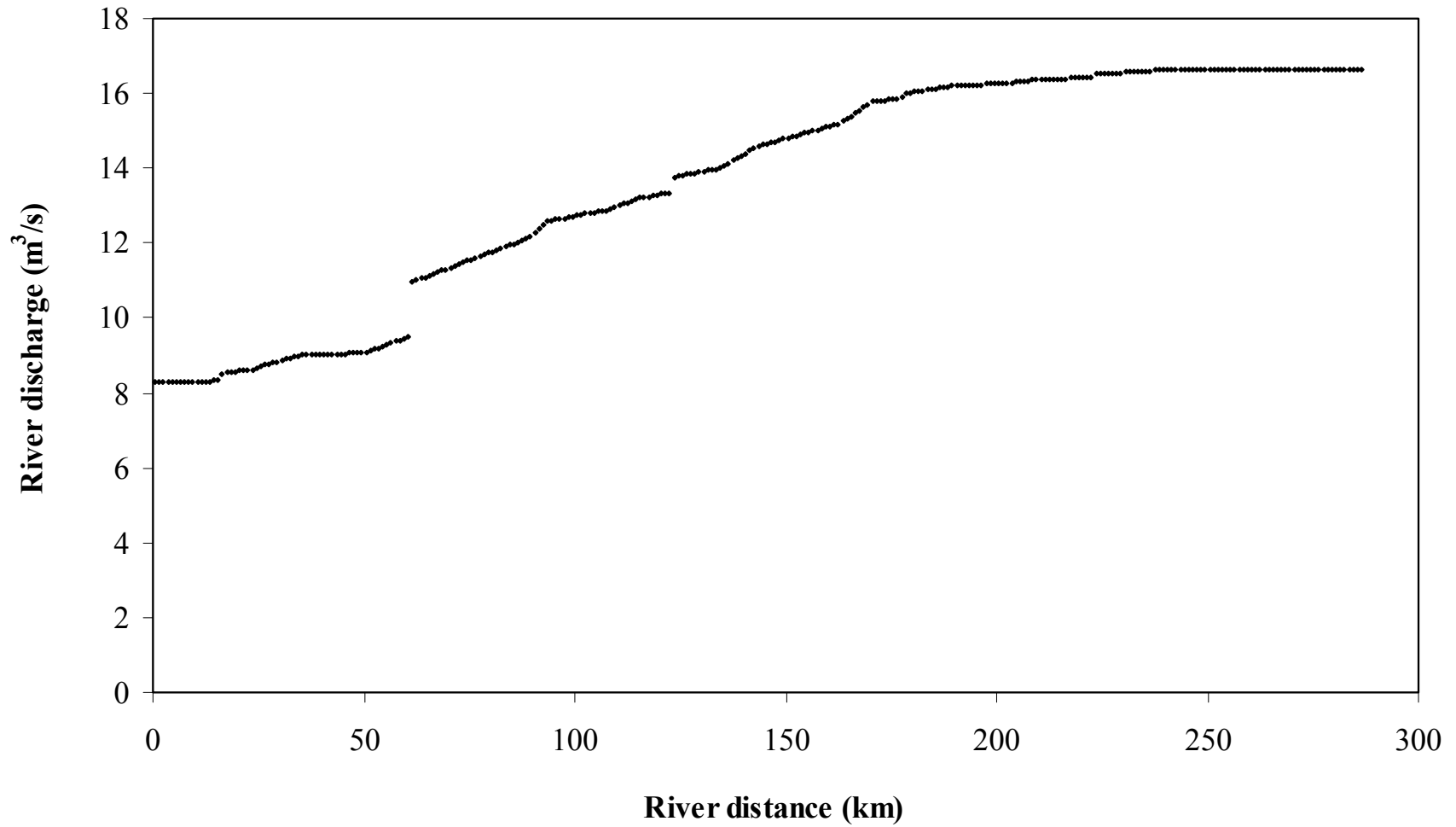


Figure 9. Simulated Assiniboine River discharge for the August/September 2002 monitoring period.

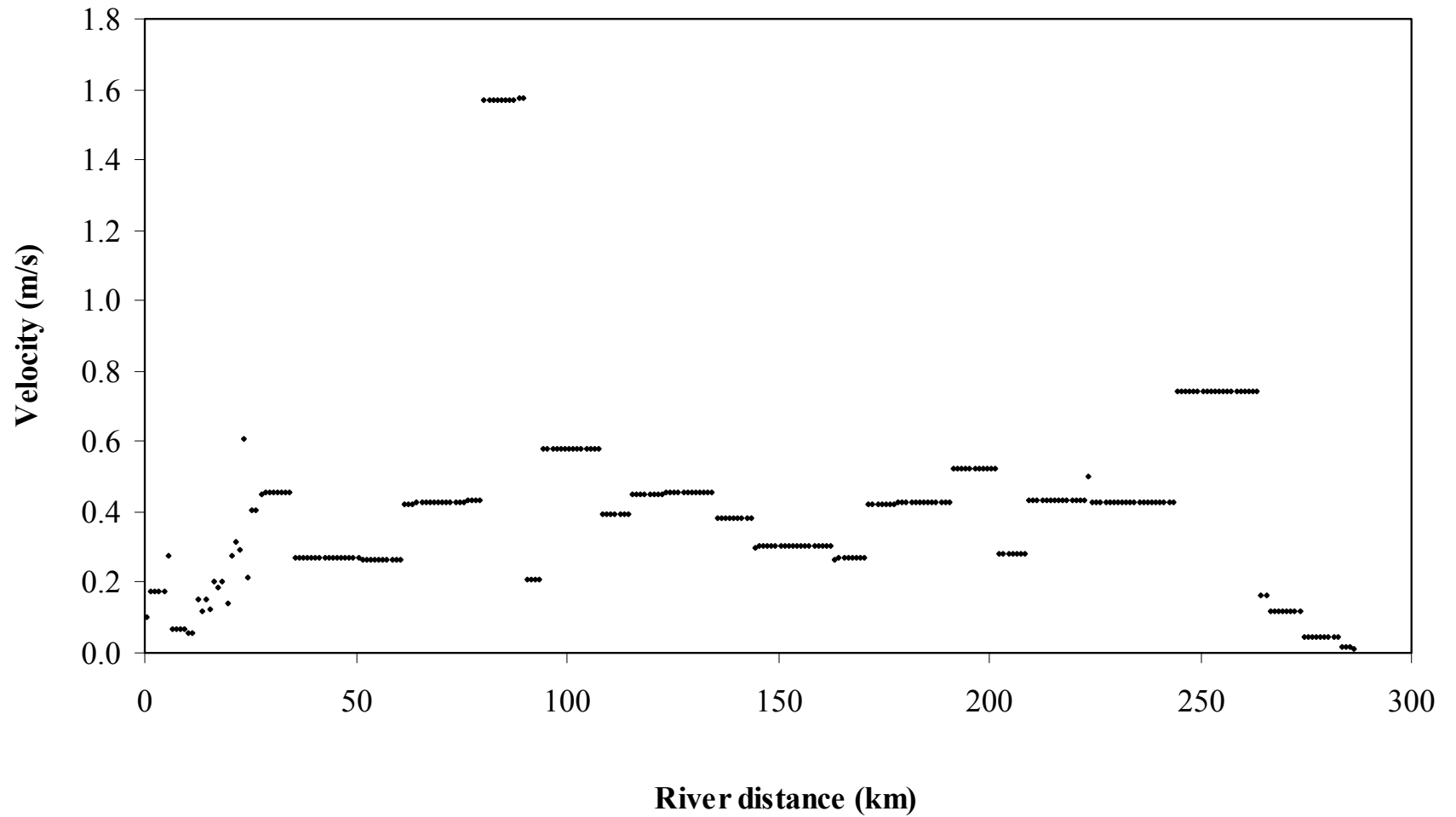


Figure 10. Simulated Assiniboine River velocities for the August/September 2002 monitoring period.

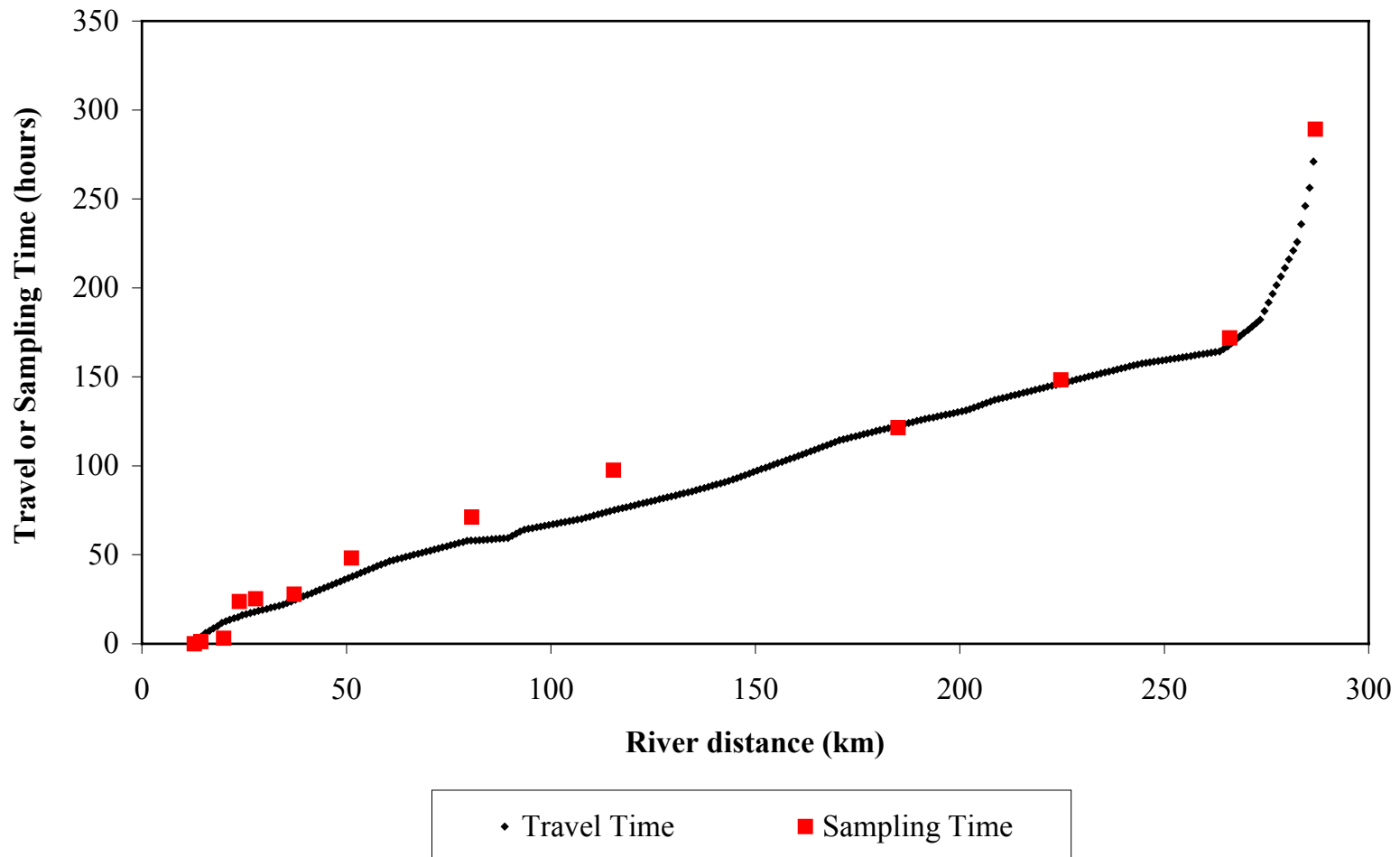


Figure 11. Simulated travel times and sampling times for the June 2002 monitoring period.

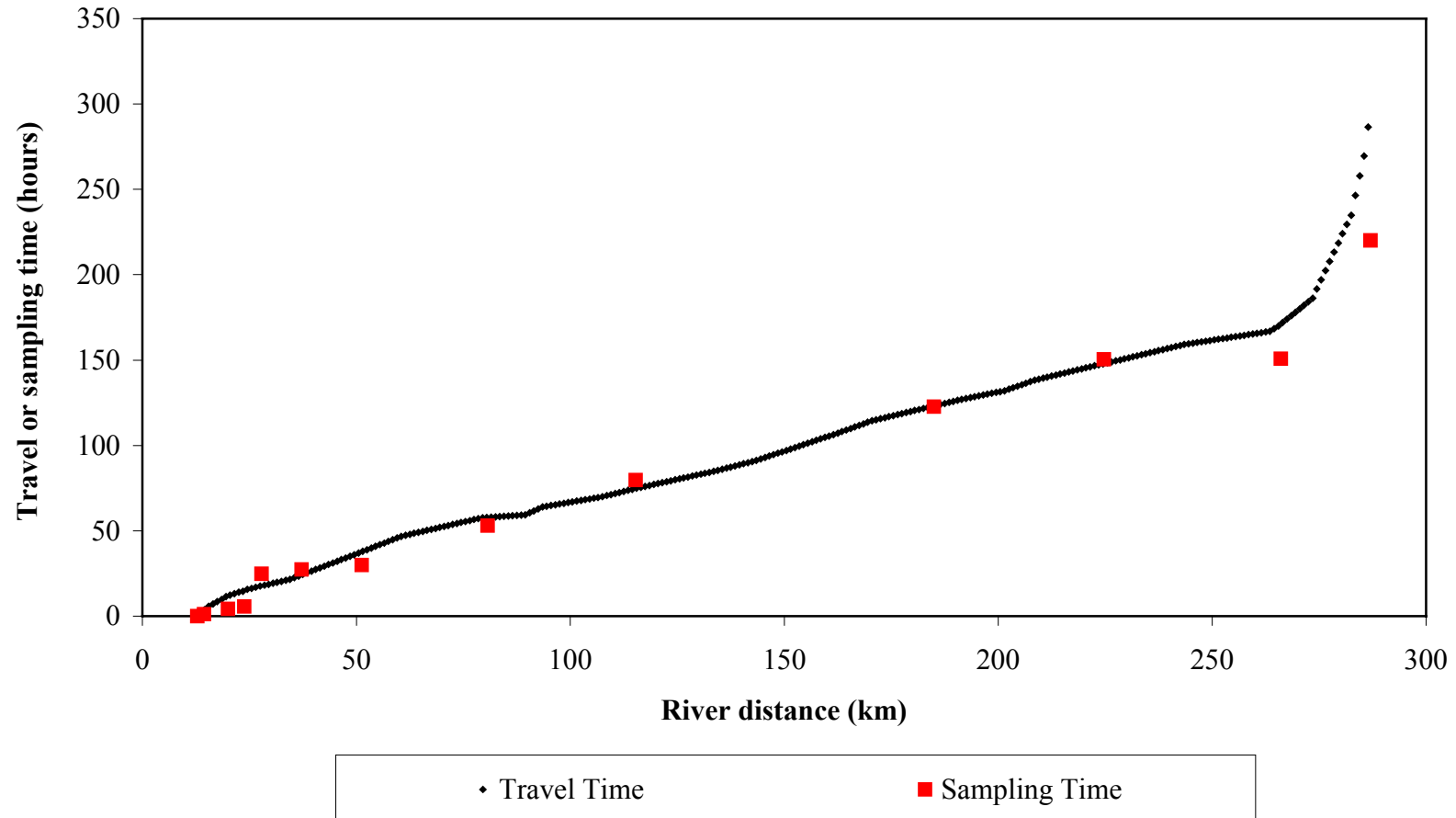


Figure 12. Simulated travel times and sampling times for the July 2002 monitoring period.

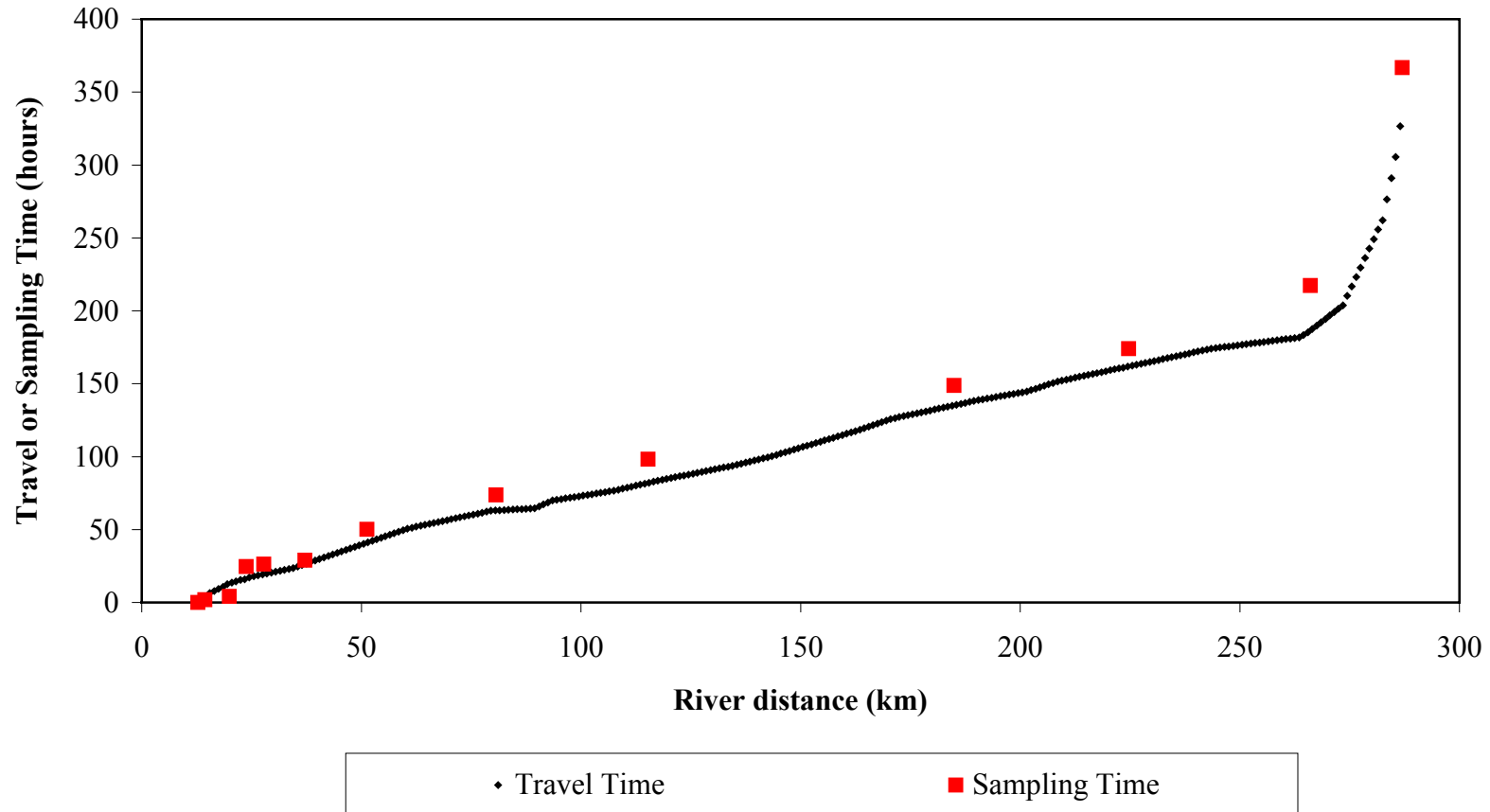


Figure 13. Simulated travel times and sampling times for the August/September 2002 monitoring period.

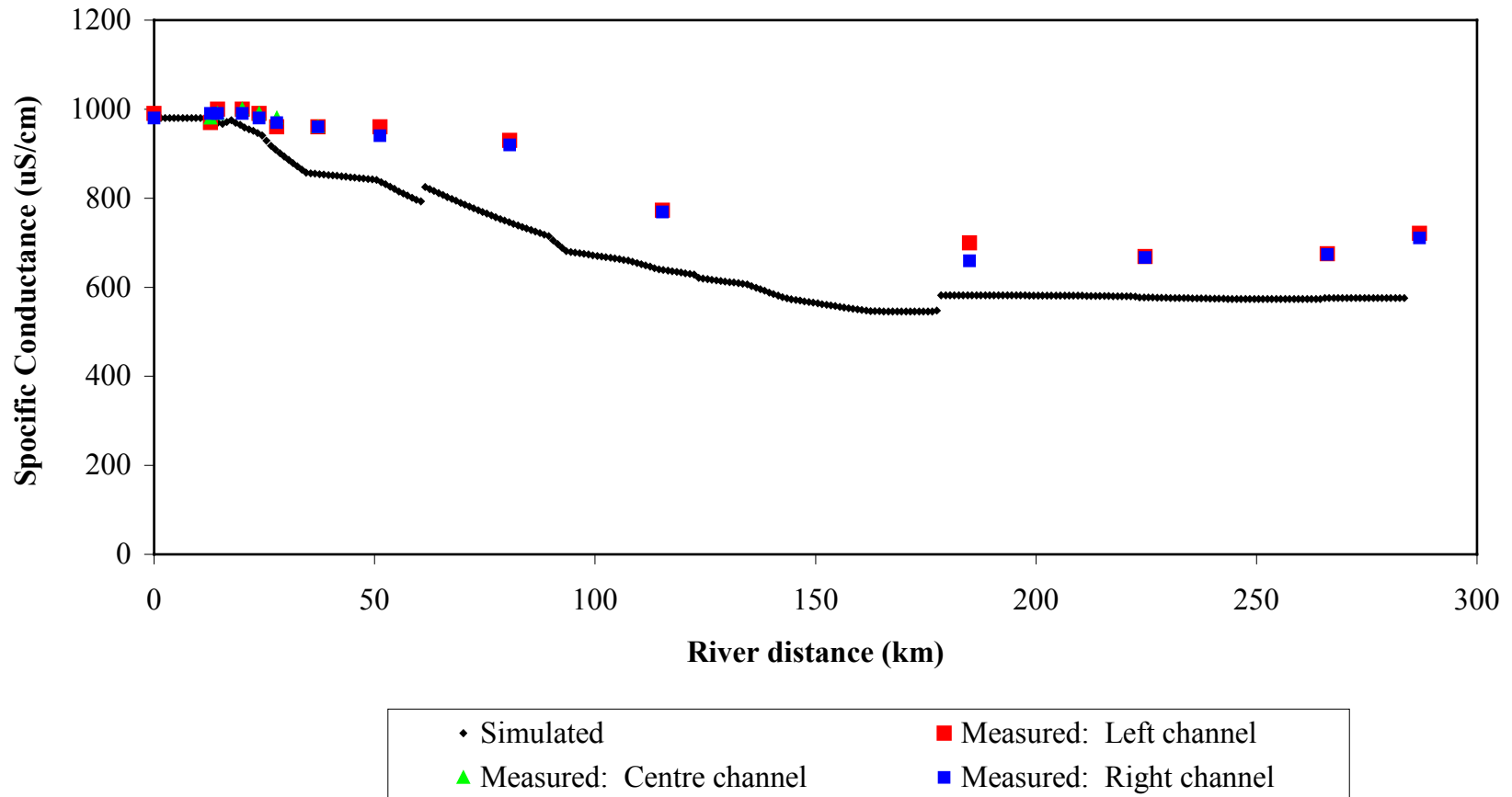


Figure 14. Simulated specific conductance, as a conservative substance, relative to measured values for the Assiniboine River: June 2002.

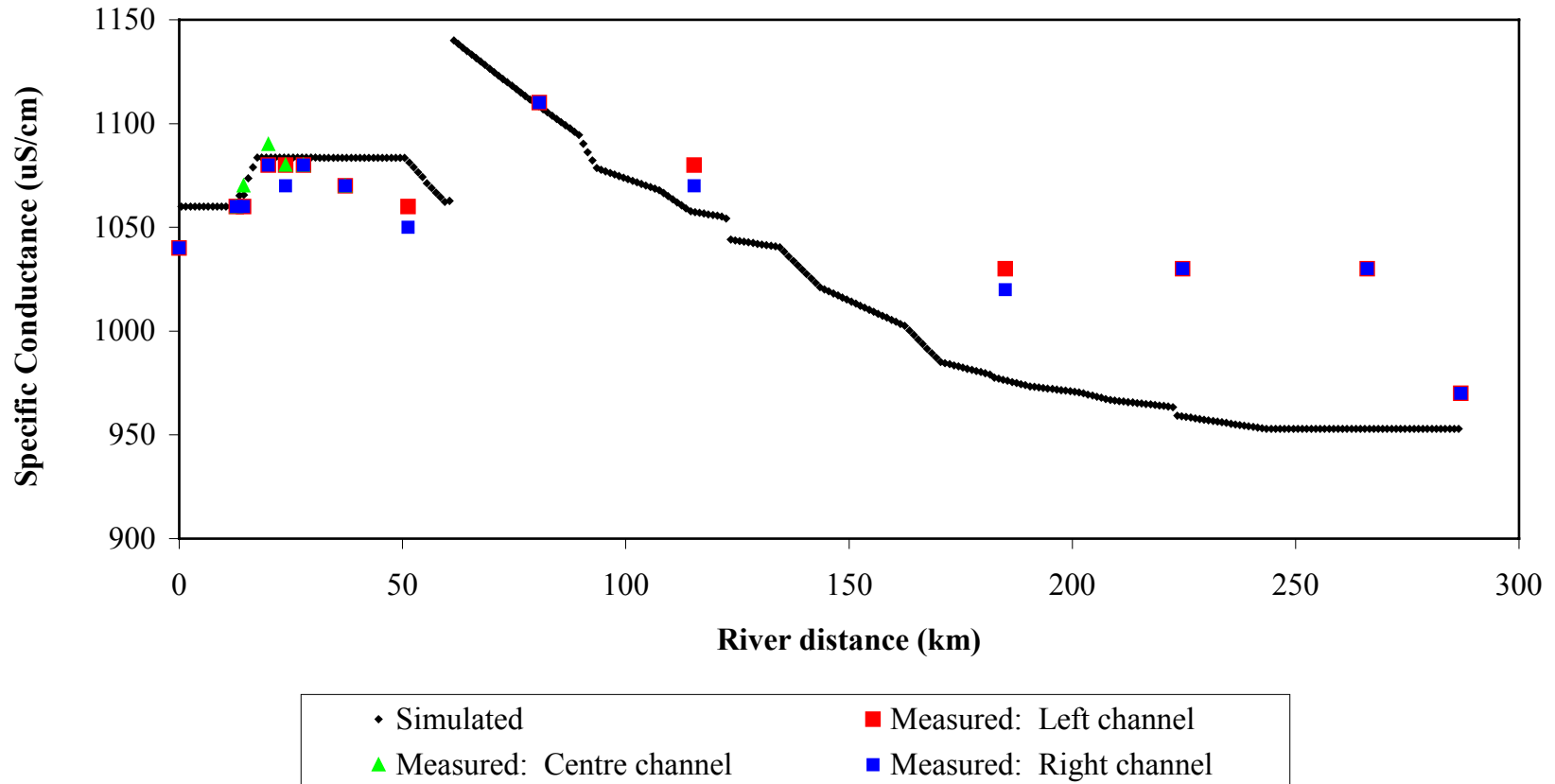


Figure 15. Simulated specific conductance, as a conservative substance, relative to measured values for the Assiniboine River: July 2002.

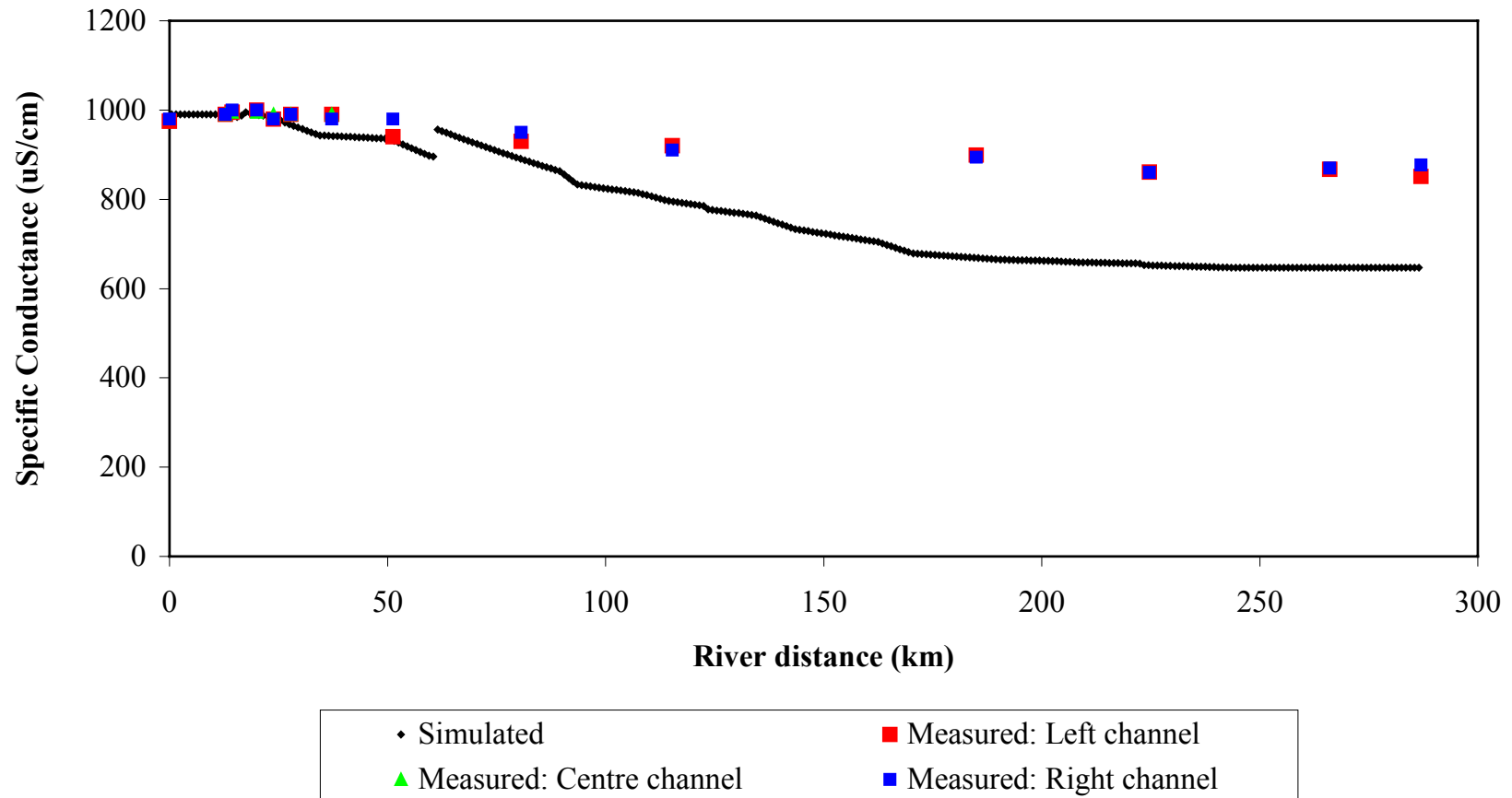


Figure 16. Simulated specific conductance, as a conservative substance, relative to measured values for the Assiniboine River: August/September 2002.

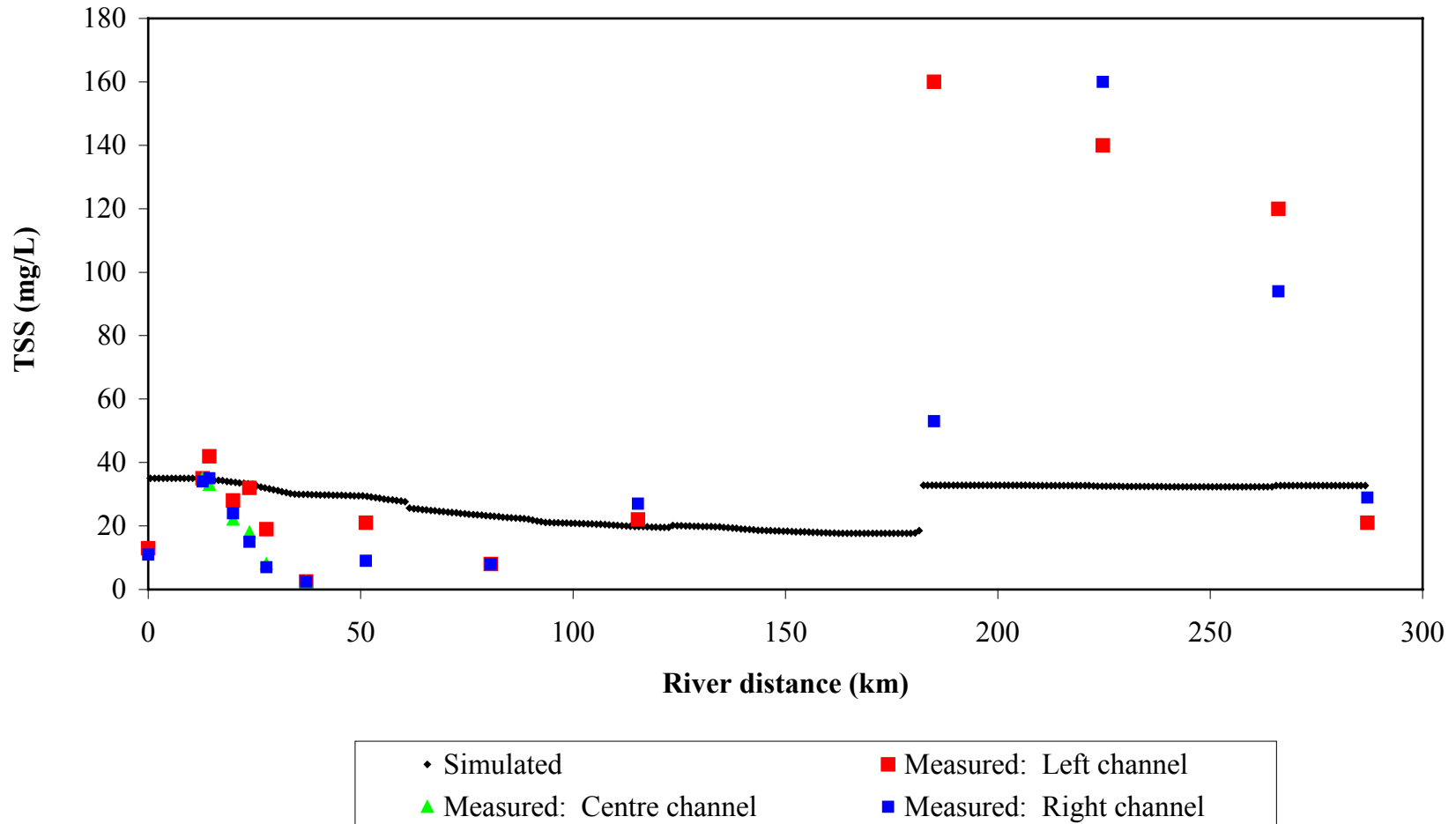


Figure 17. Simulated TSS, as a conservative substance, relative to measured values for the Assiniboine River: June 2002.

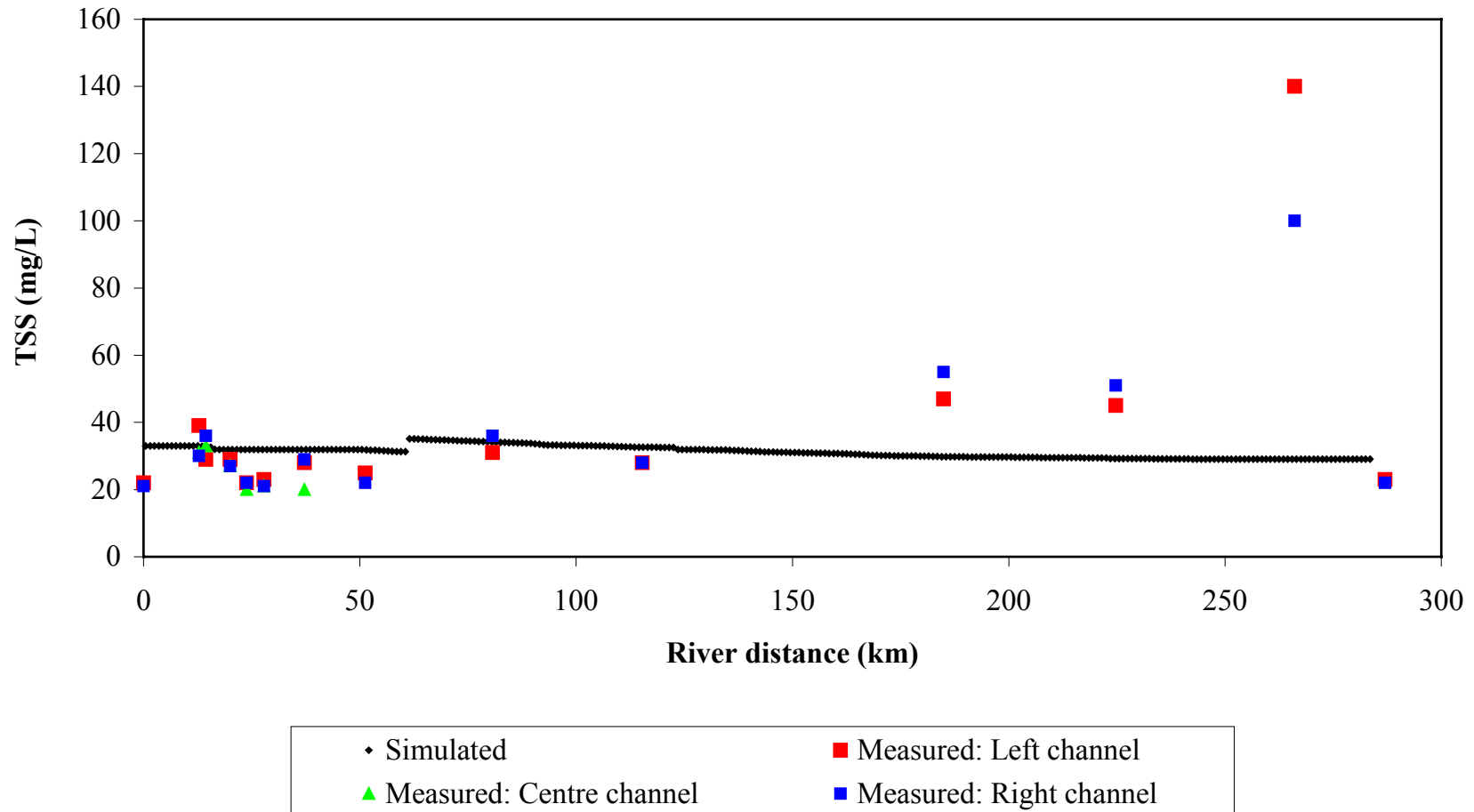


Figure 18. Simulated TSS, as a conservative substance, relative to measured values for the Assiniboine River: July 2002.

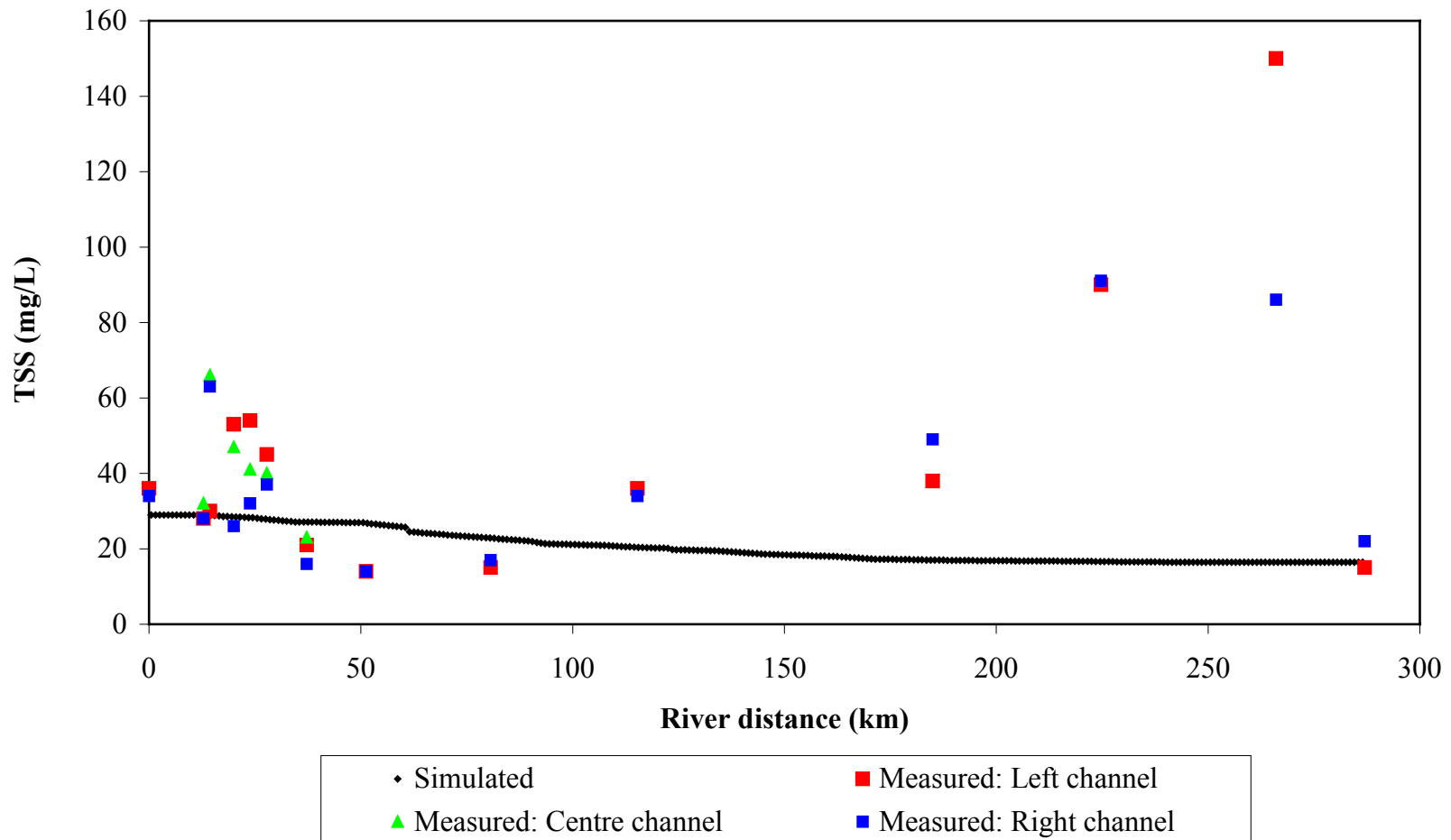


Figure 19. Simulated TSS, as a conservative substance, relative to measured values for the Assiniboine River: August/September 2002.

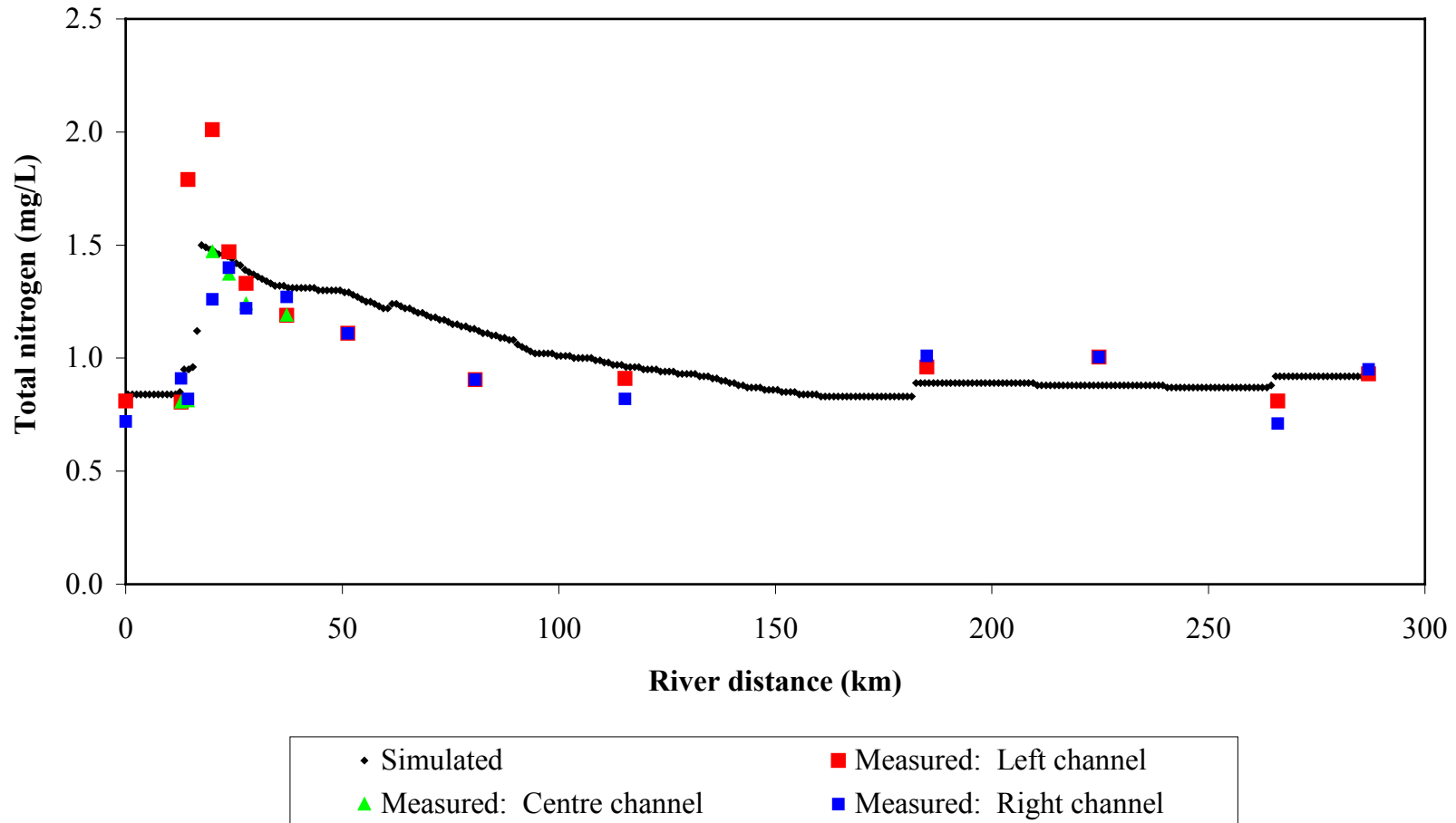


Figure 20. Results of a mass-balance simulation for total nitrogen, relative to measured values for the Assiniboine River: June 2002.

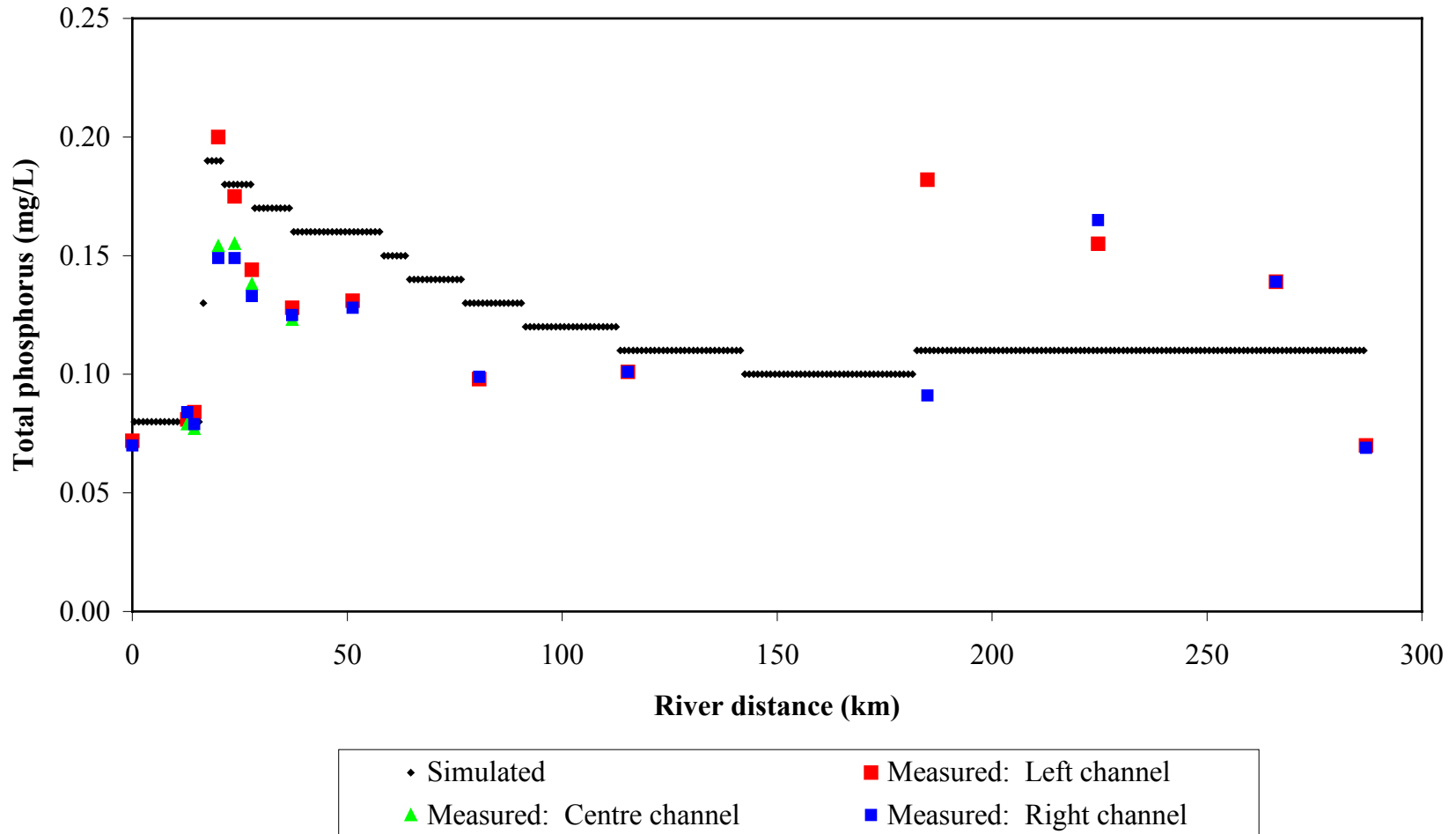


Figure 21. Results of a mass-balance simulation for total phosphorus, relative to measured values for the Assiniboine River: June 2002.

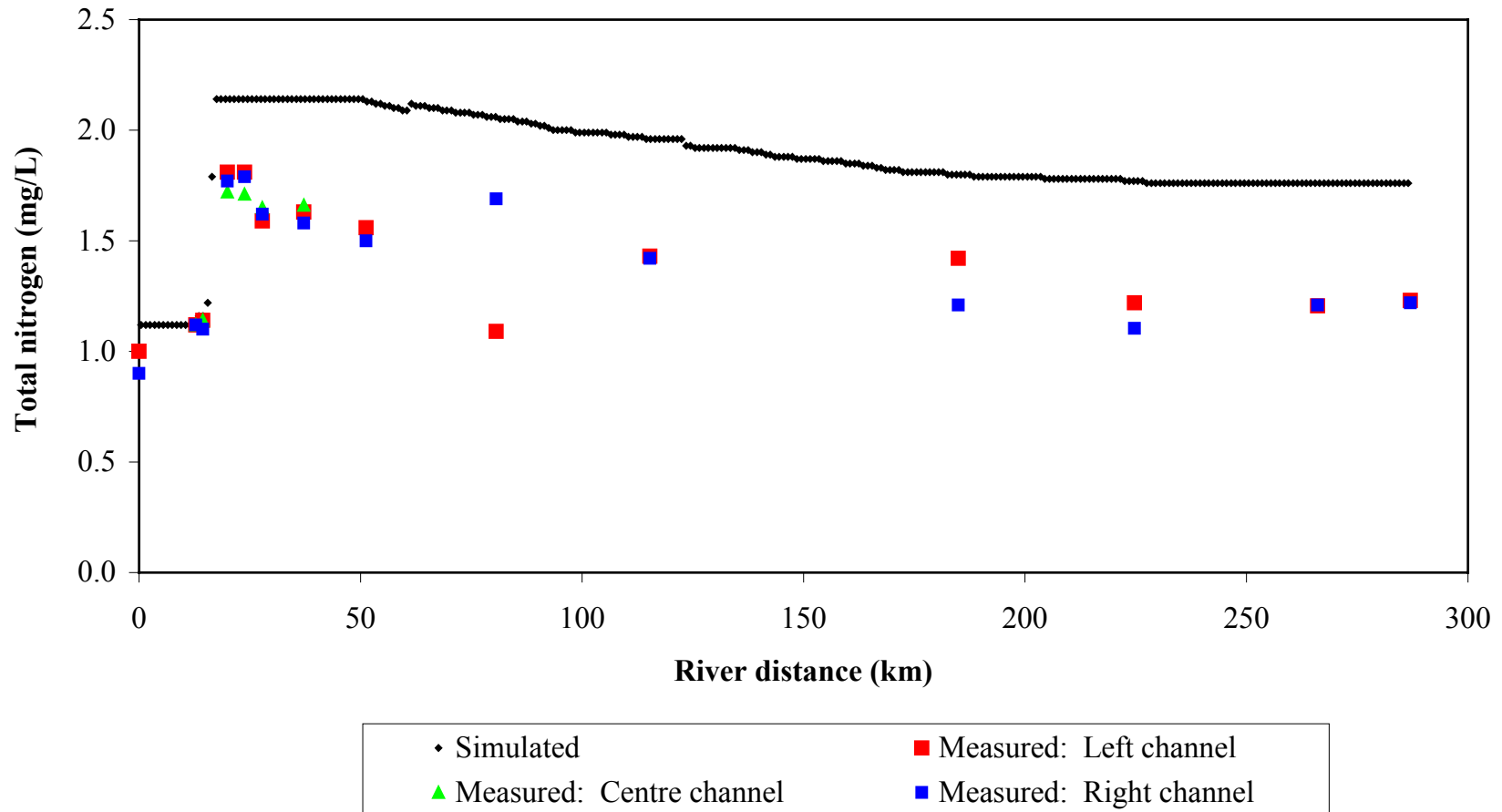


Figure 22. Results of a mass-balance simulation for total nitrogen, relative to measured values for the Assiniboine River: July 2002.

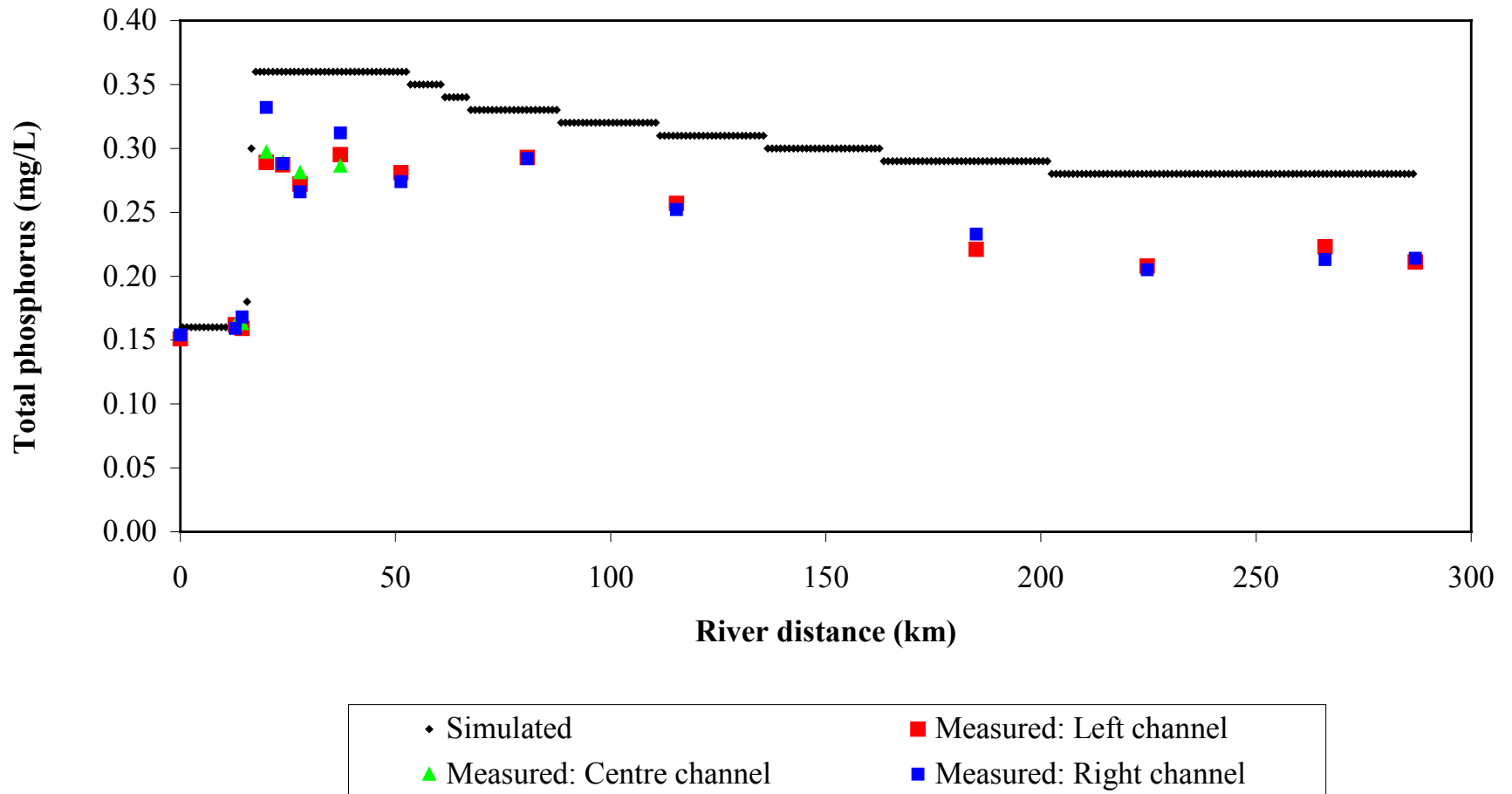


Figure 23. Results of a mass-balance simulation for total phosphorus, relative to measured values for the Assiniboine River: July 2002.

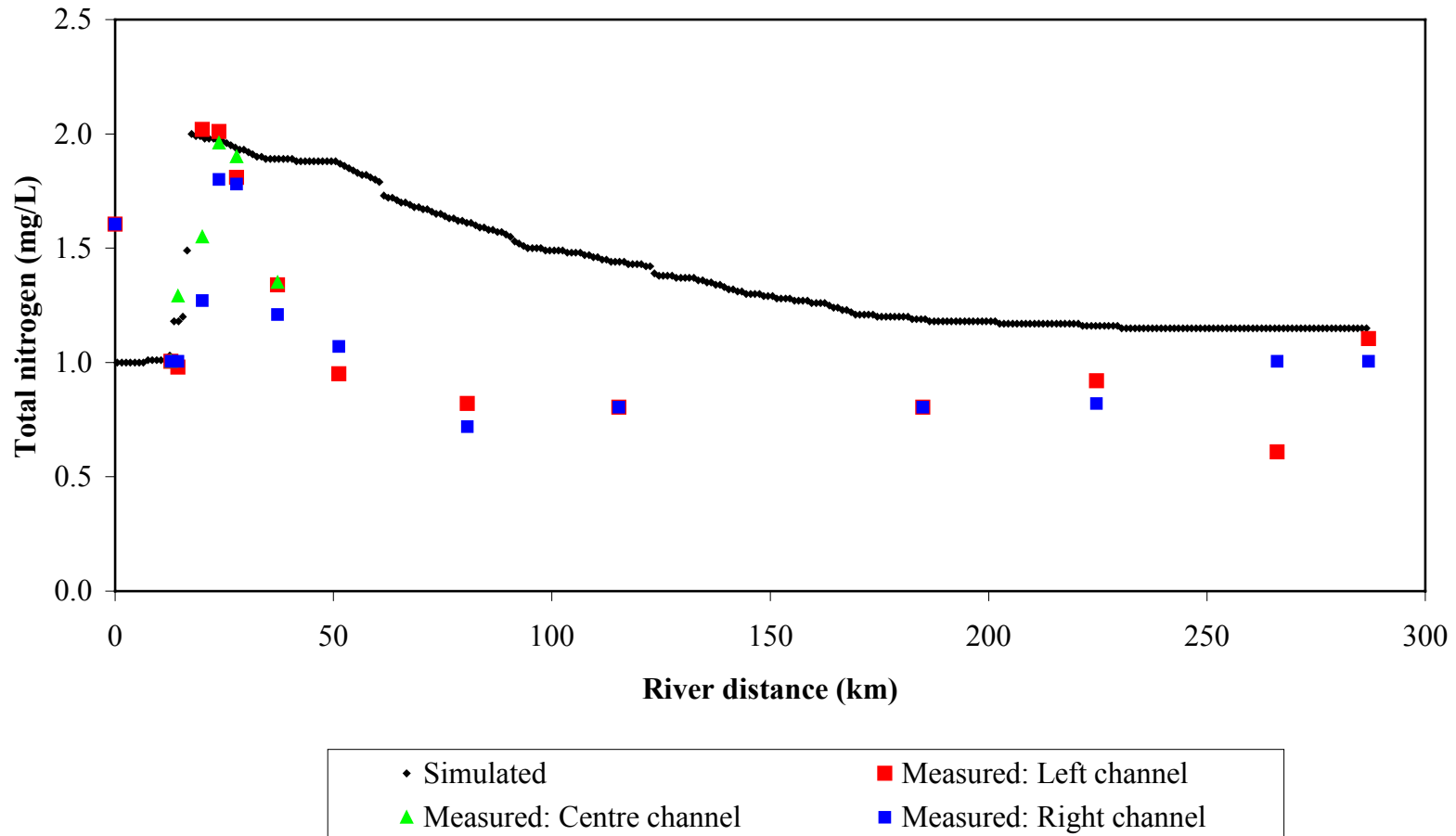


Figure 24. Results of a mass-balance simulation for total nitrogen, relative to measured values for the Assiniboine River: August/September 2002.

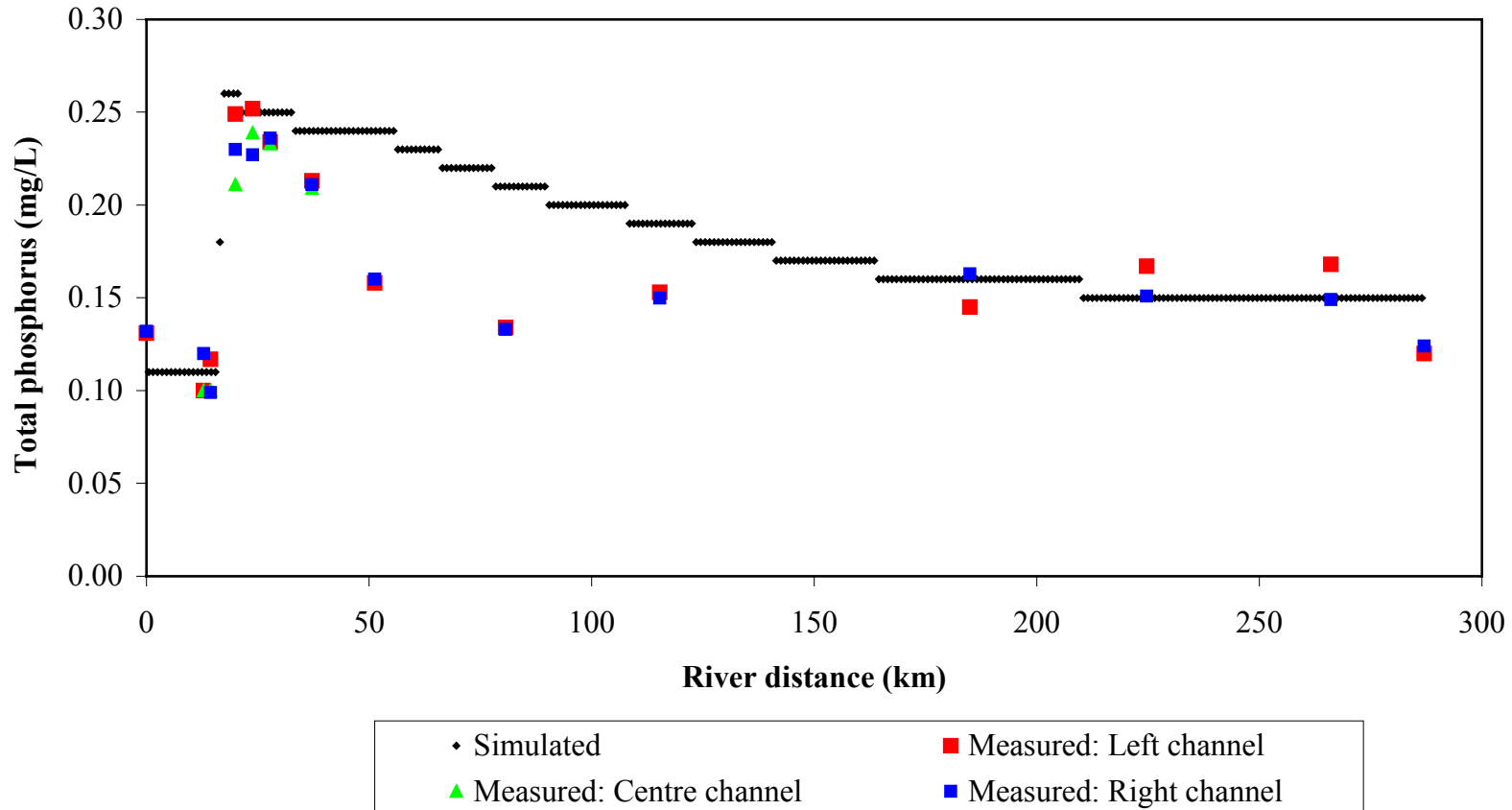


Figure 25. Results of a mass-balance simulation for total phosphorus, relative to measured values for the Assiniboine River: August/September 2002.

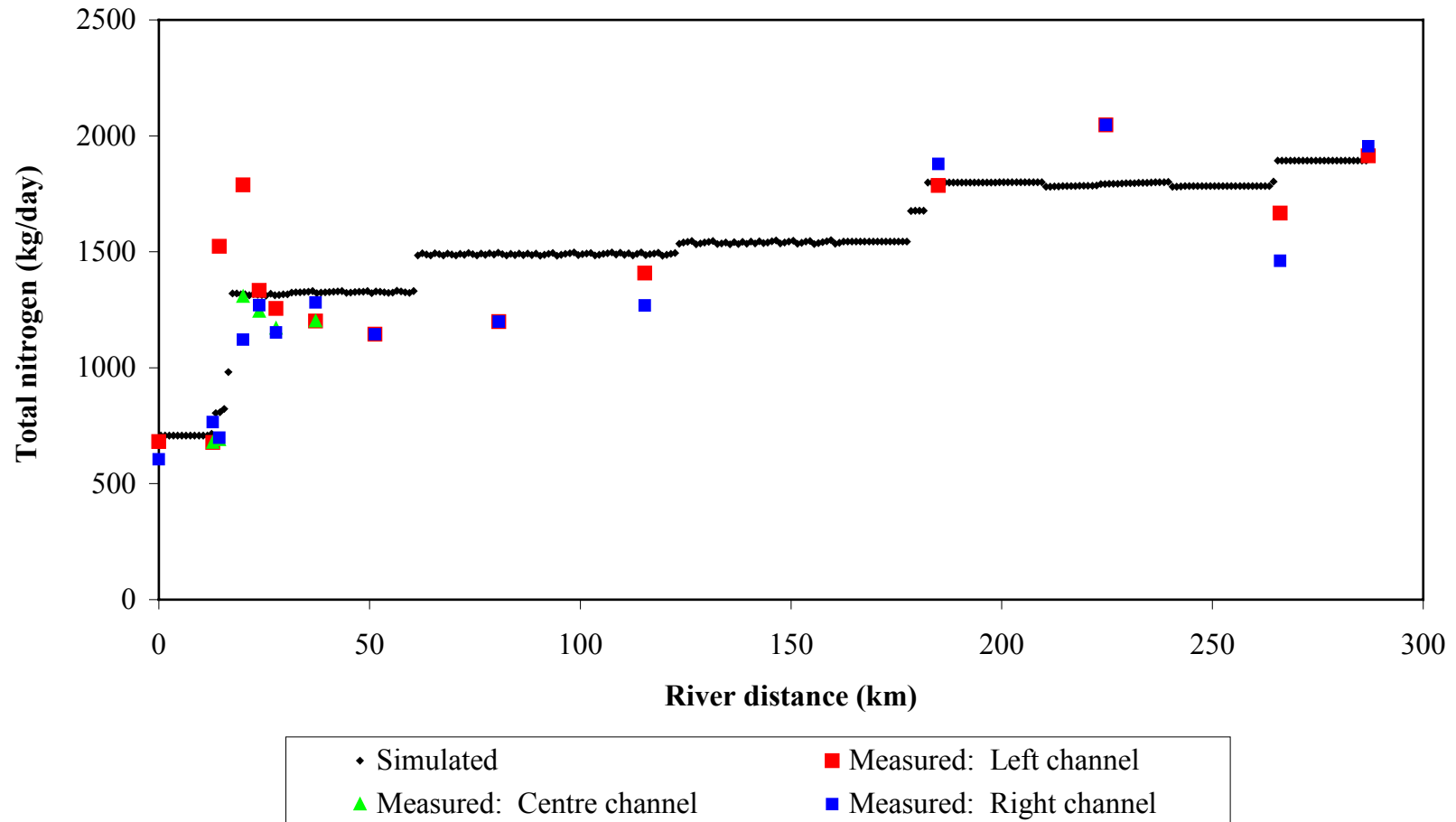


Figure 26. Results of a mass-balance simulation for total nitrogen, expressed as loads, relative to measured loads for the Assiniboine River: June 2002. Loads were calculated based on modeled river discharges and simulated or measured total nitrogen concentrations.

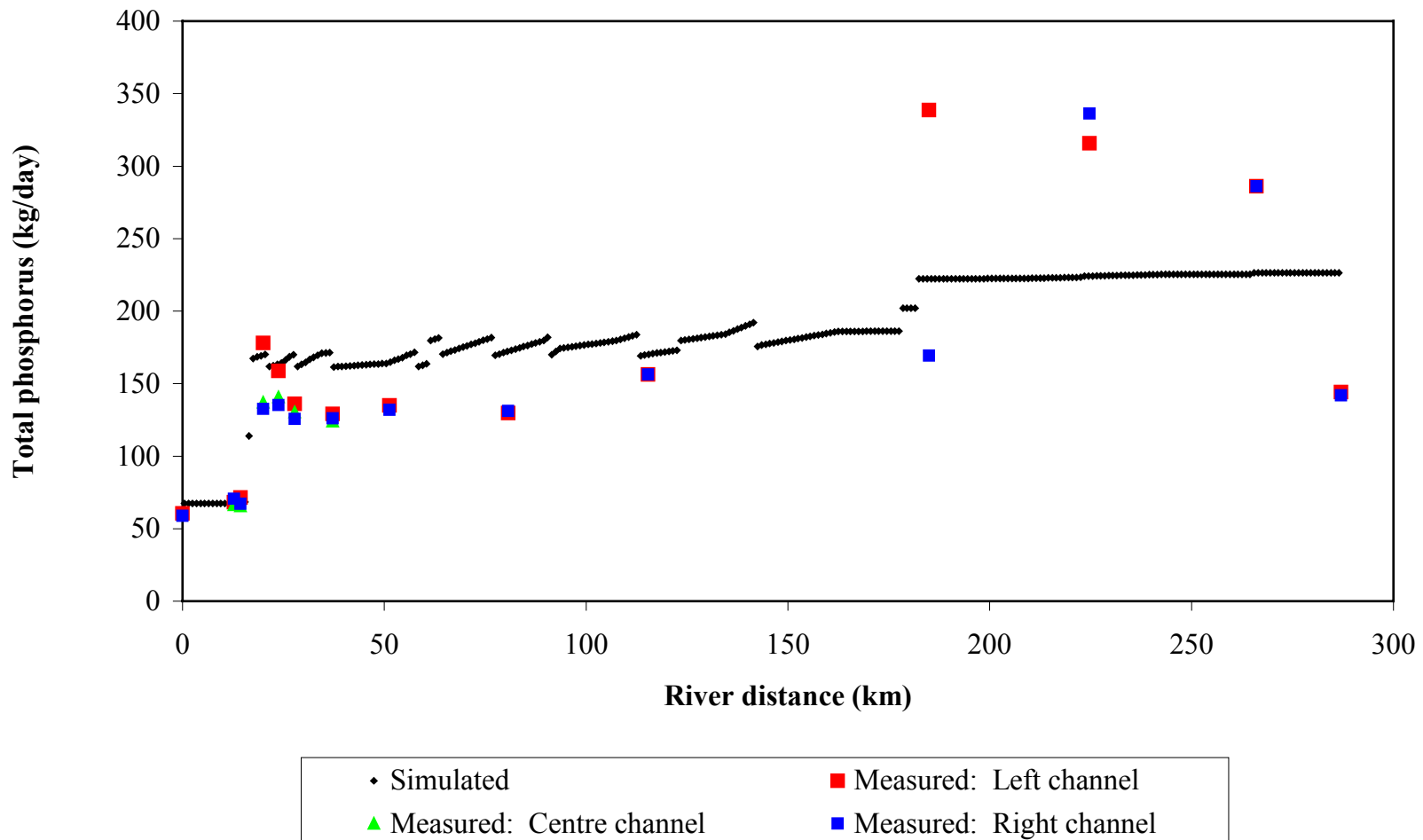


Figure 27. Results of a mass-balance simulation for total phosphorus, expressed as loads, relative to measured loads for the Assiniboine River: June 2002. Loads were calculated based on modeled river discharges and simulated or measured total phosphorus concentrations.

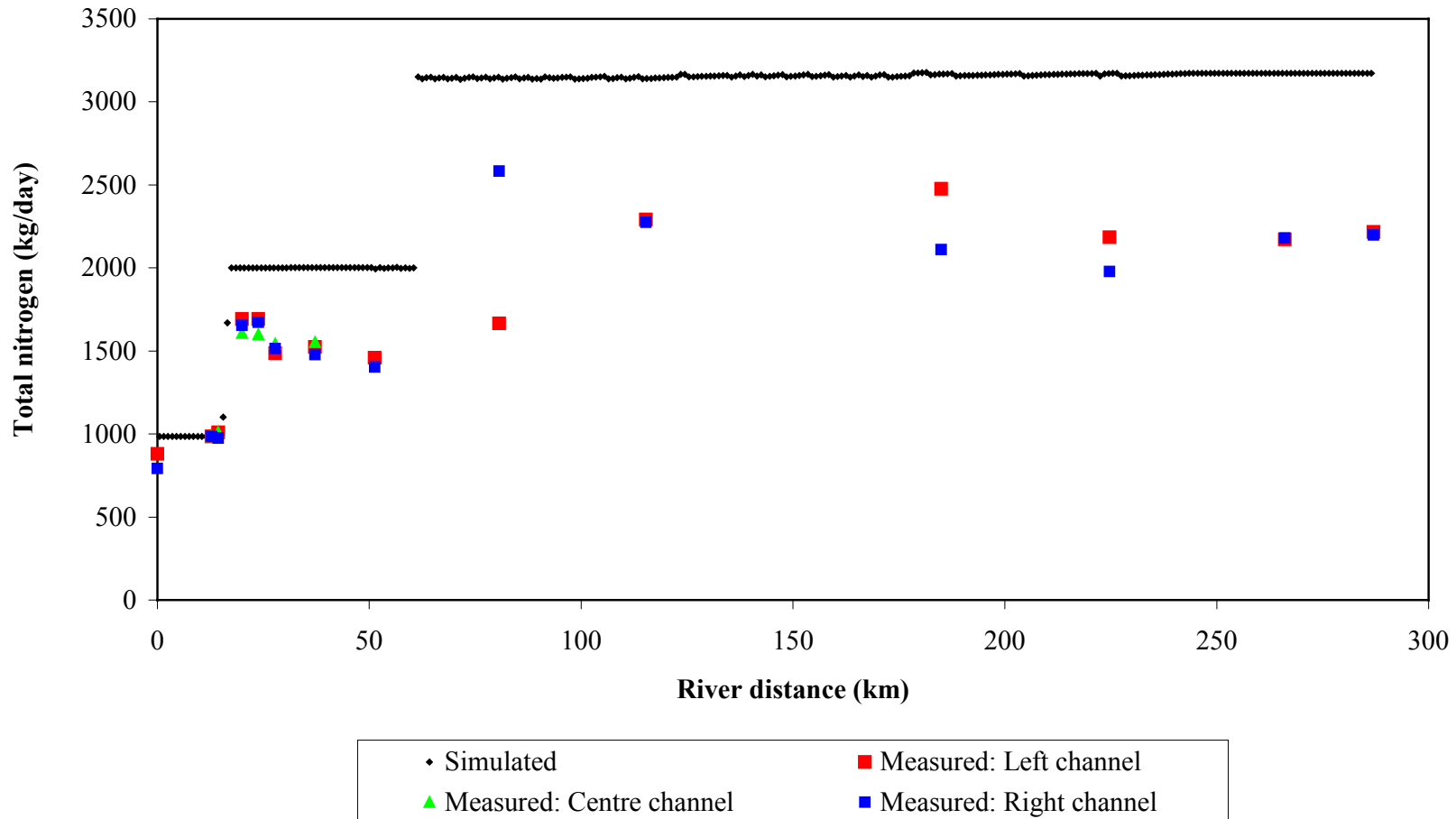


Figure 28. Results of a mass-balance simulation for total nitrogen, expressed as loads, relative to measured loads for the Assiniboine River: July 2002. Loads were calculated based on modeled river discharges and simulated or measured total nitrogen concentrations.

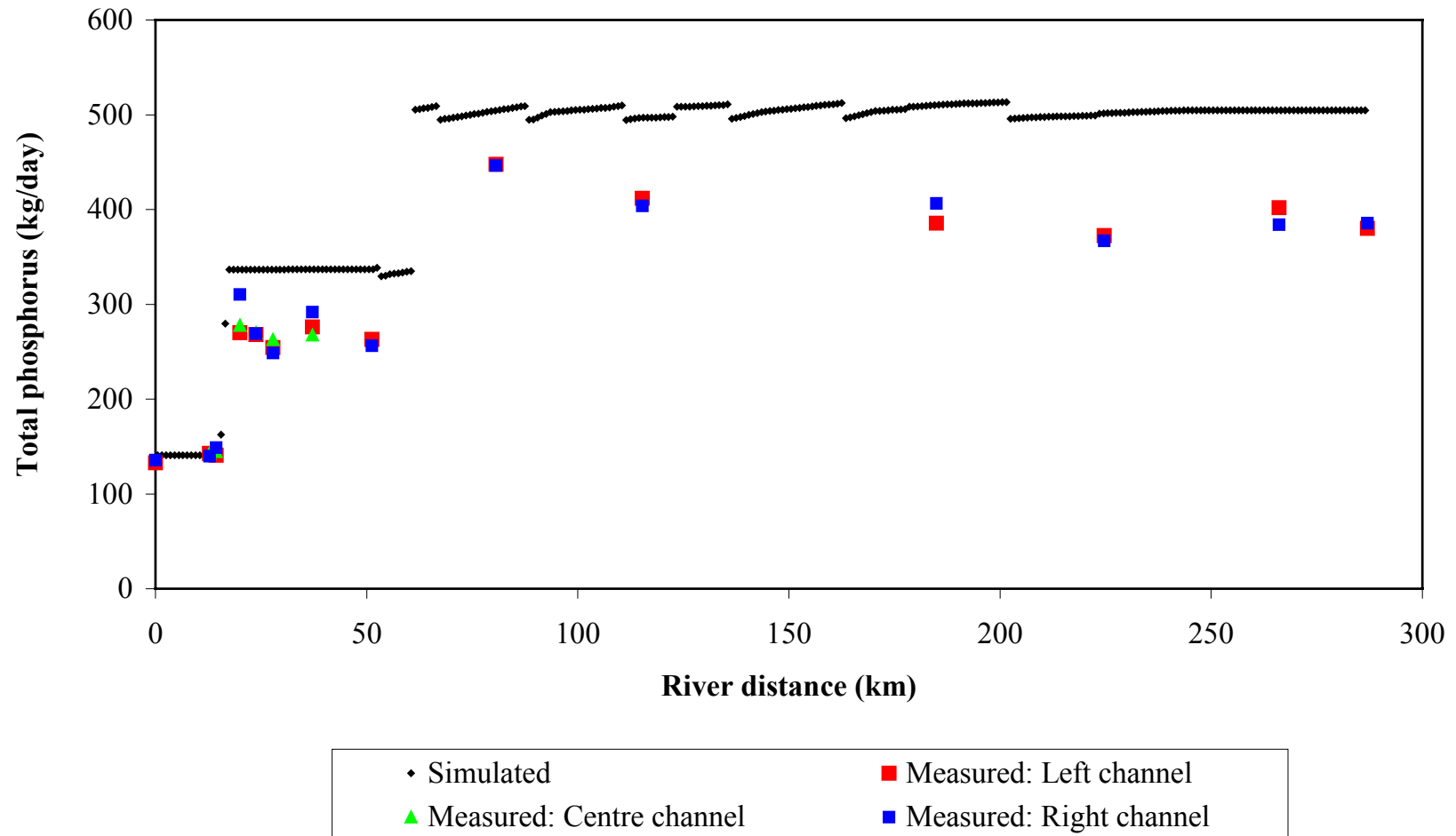


Figure 29. Results of a mass-balance simulation for total phosphorus, expressed as loads, relative to measured loads for the Assiniboine River: July 2002. Loads were calculated based on modeled river discharges and simulated or measured total phosphorus concentrations.

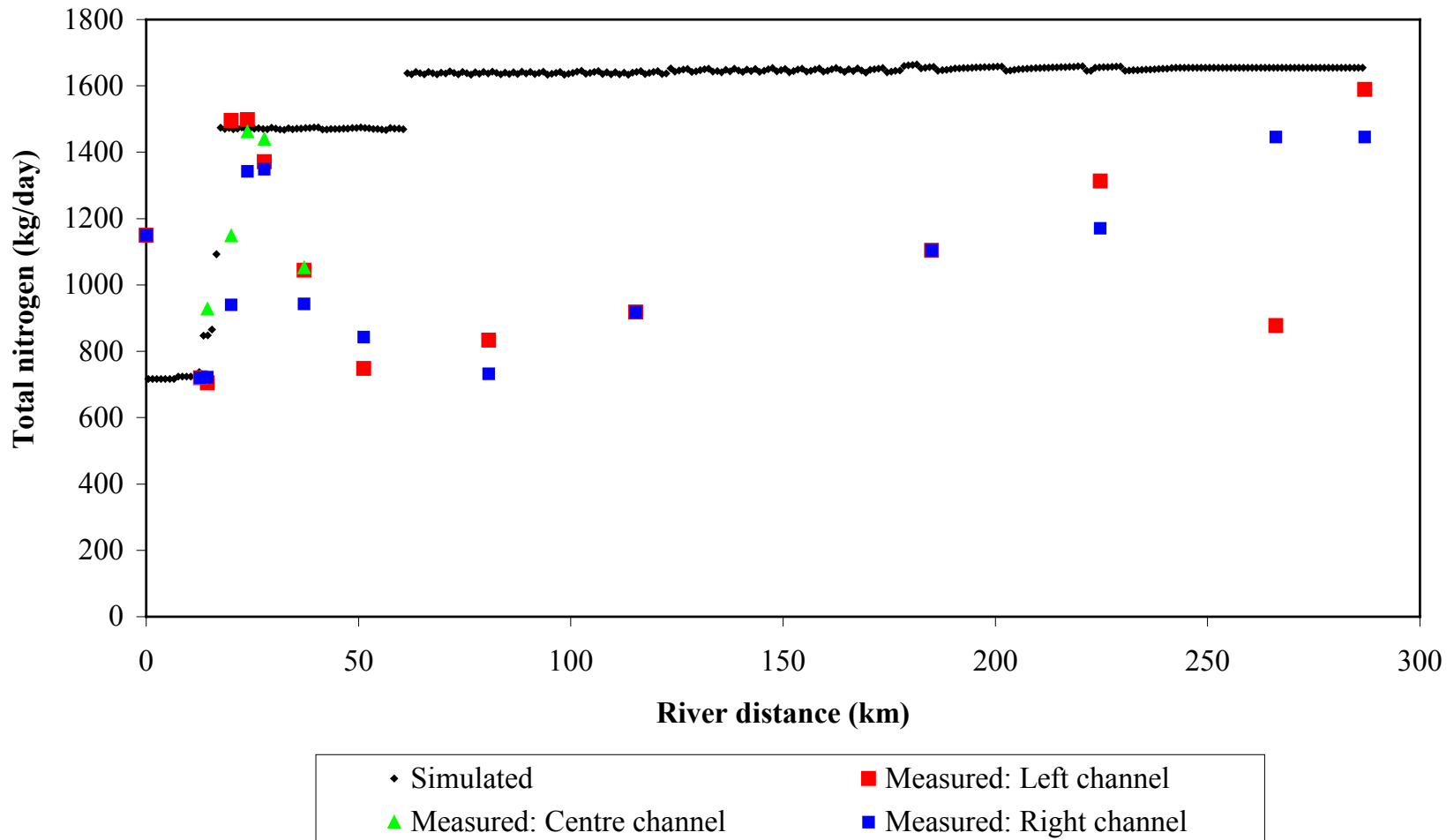


Figure 30. Results of a mass-balance simulation for total nitrogen, expressed as loads, relative to measured loads for the Assiniboine River: August/September 2002. Loads were calculated based on modeled river discharges and simulated or measured total nitrogen concentrations.

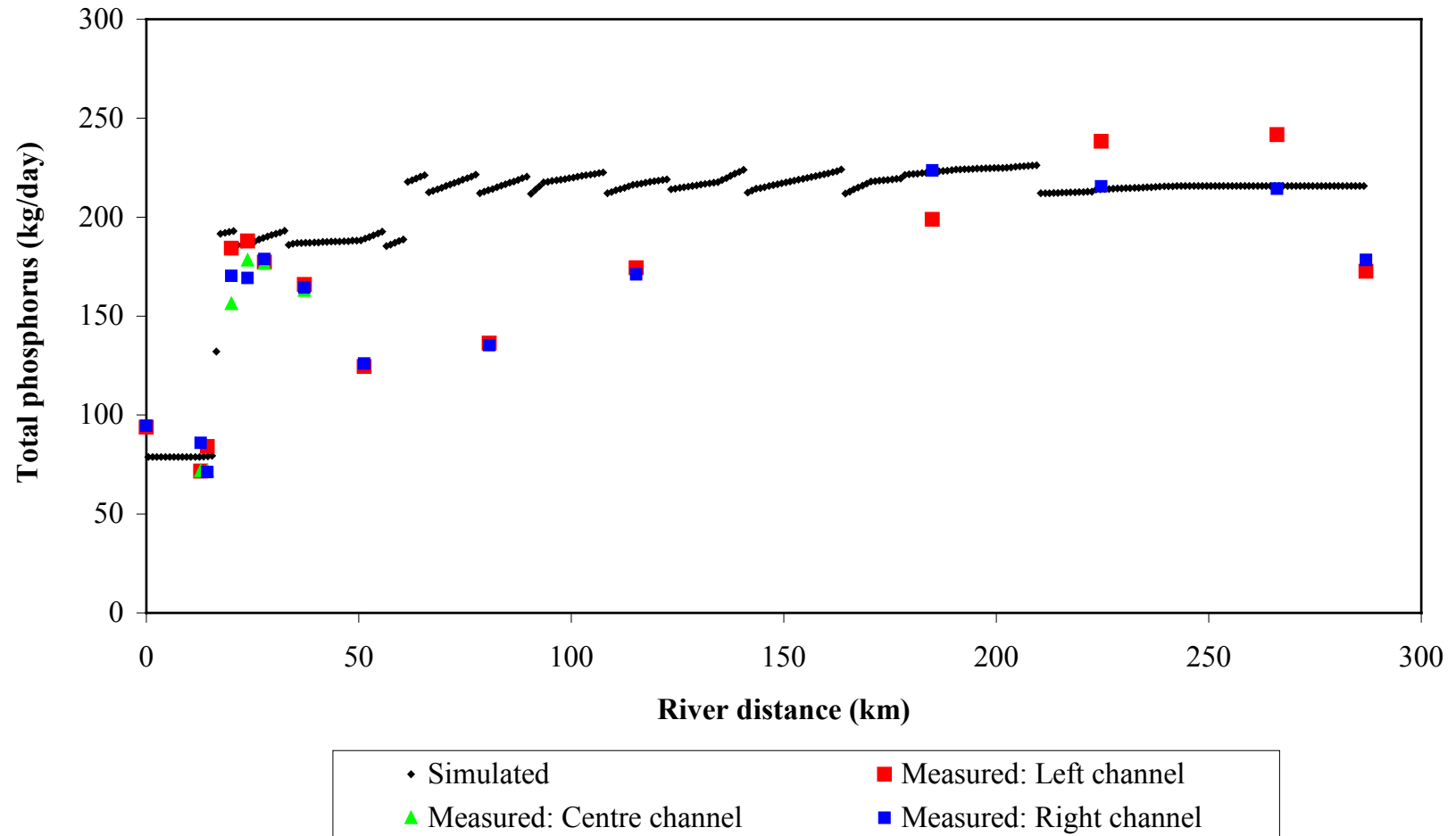


Figure 31. Results of a mass-balance simulation for total phosphorus, expressed as loads, relative to measured loads for the Assiniboine River: August/September 2002. Loads were calculated based on modeled river discharges and simulated or measured total phosphorus concentrations.

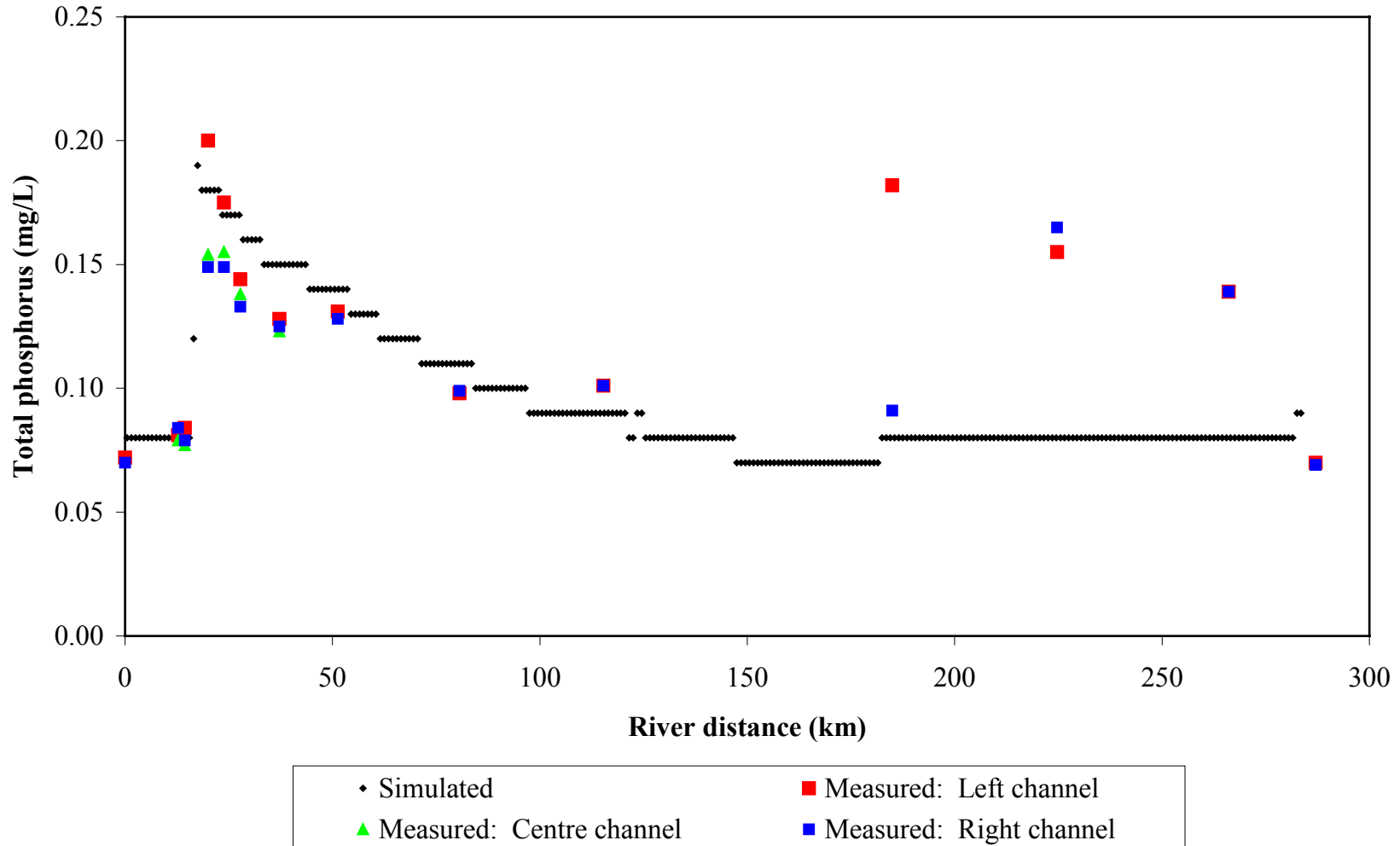


Figure 32. Results of model calibration for total phosphorus, relative to measured concentrations: June 2002.

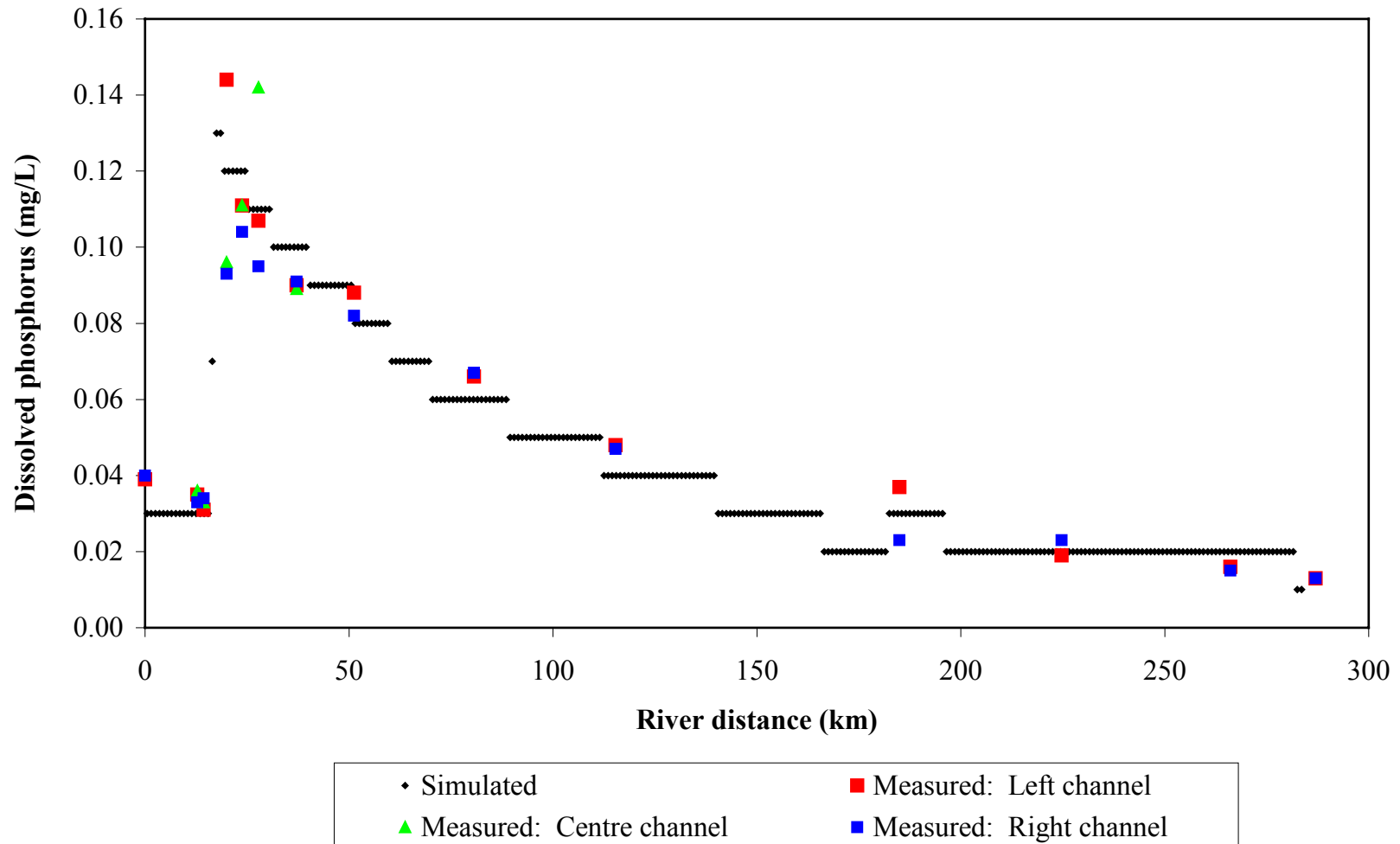


Figure 33. Results of model calibration for dissolved phosphorus, relative to measured concentrations: June 2002.

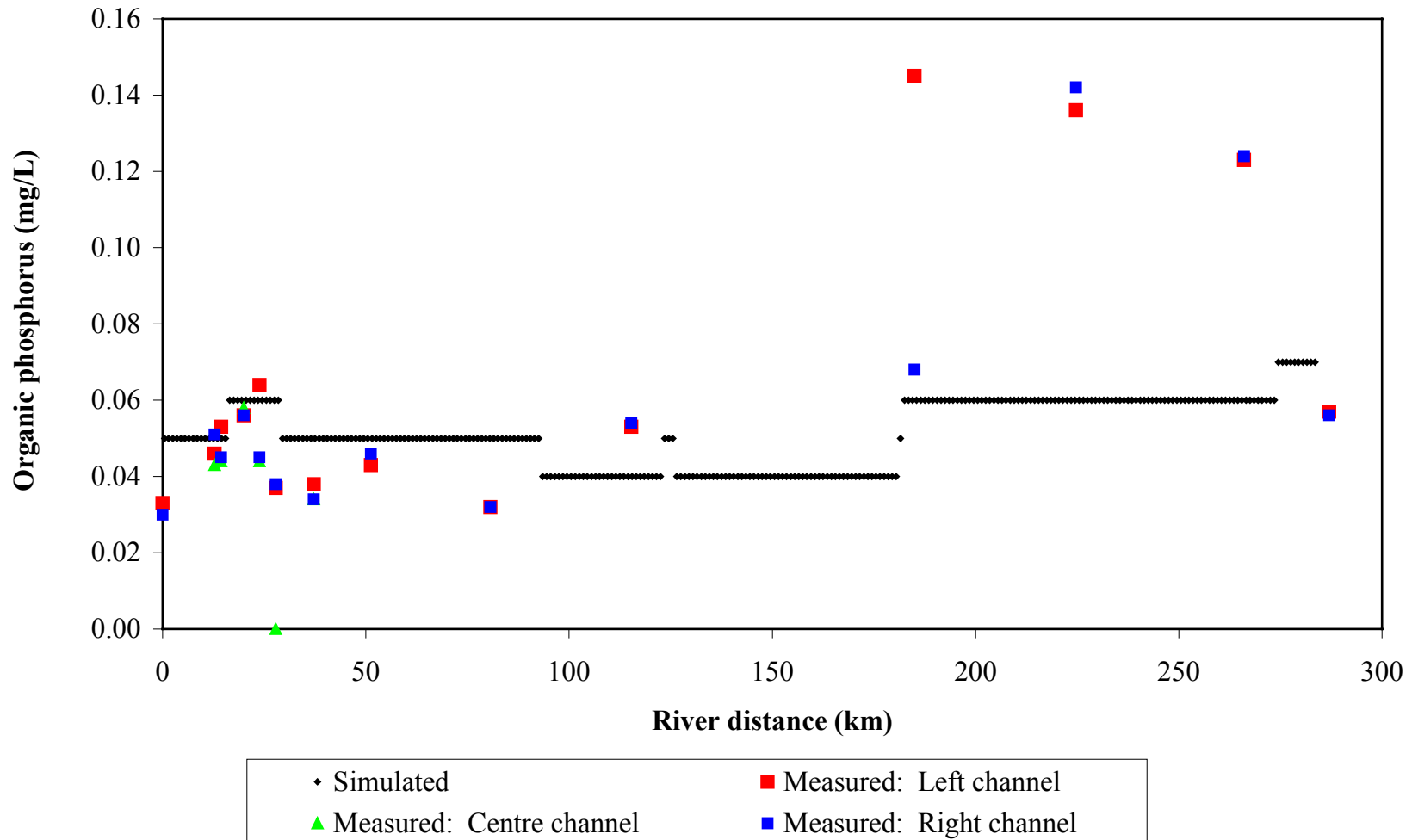


Figure 34. Results of model calibration for organic phosphorus, relative to measured concentrations: June 2002.

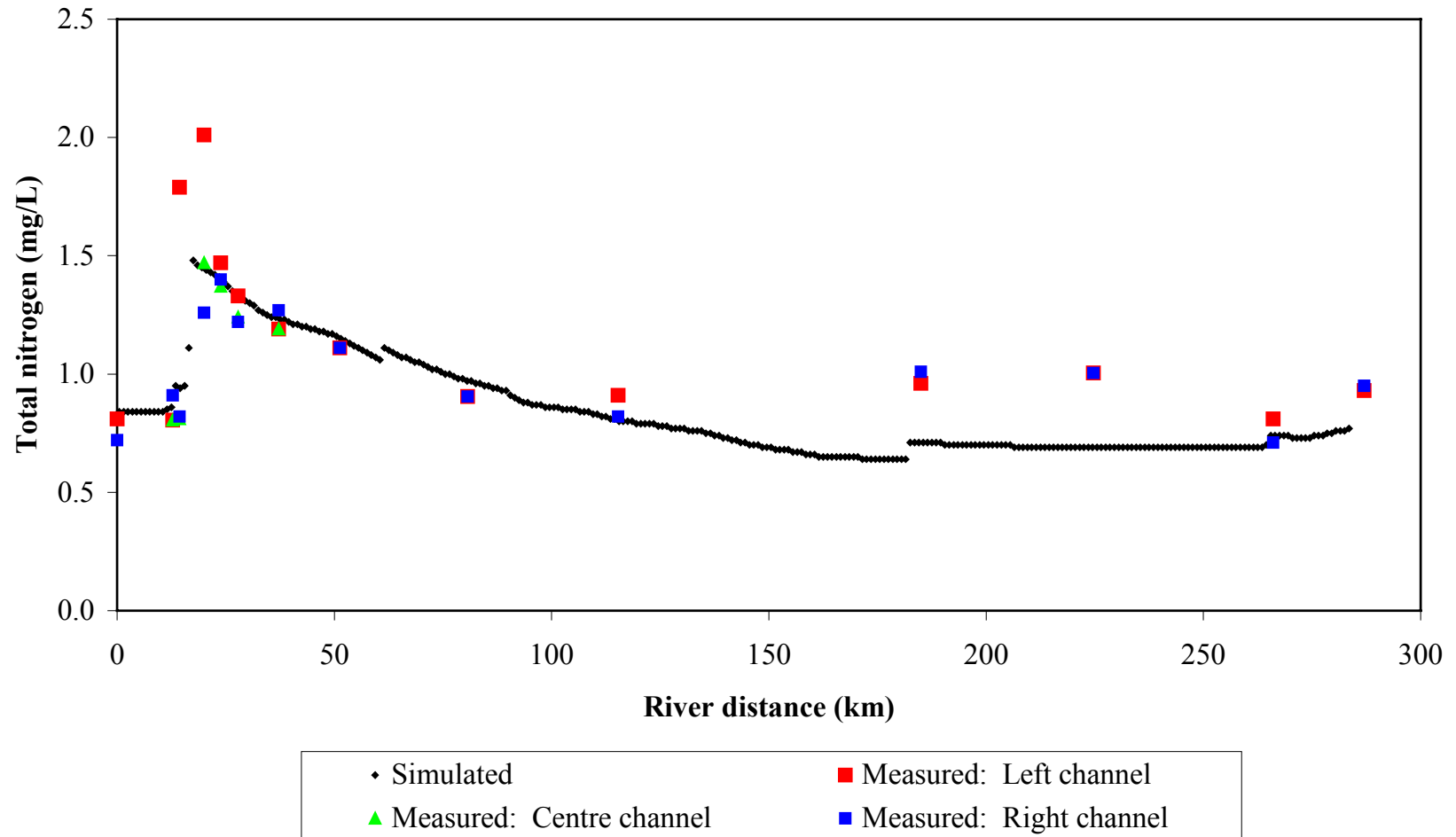


Figure 35. Results of model calibration for total nitrogen, relative to measured concentrations: June 2002.

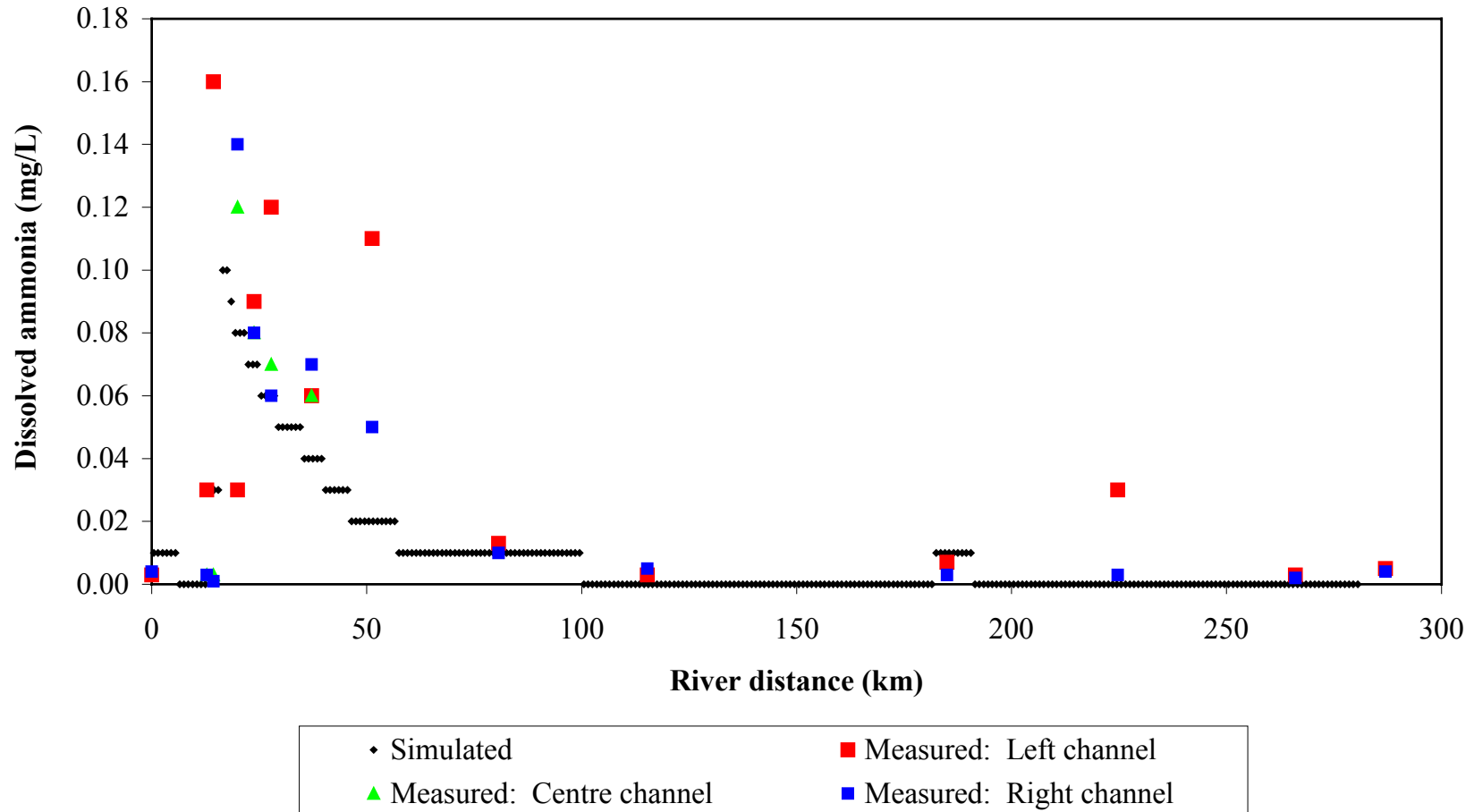


Figure 36. Results of model calibration for ammonia, relative to measured concentrations: June 2002.

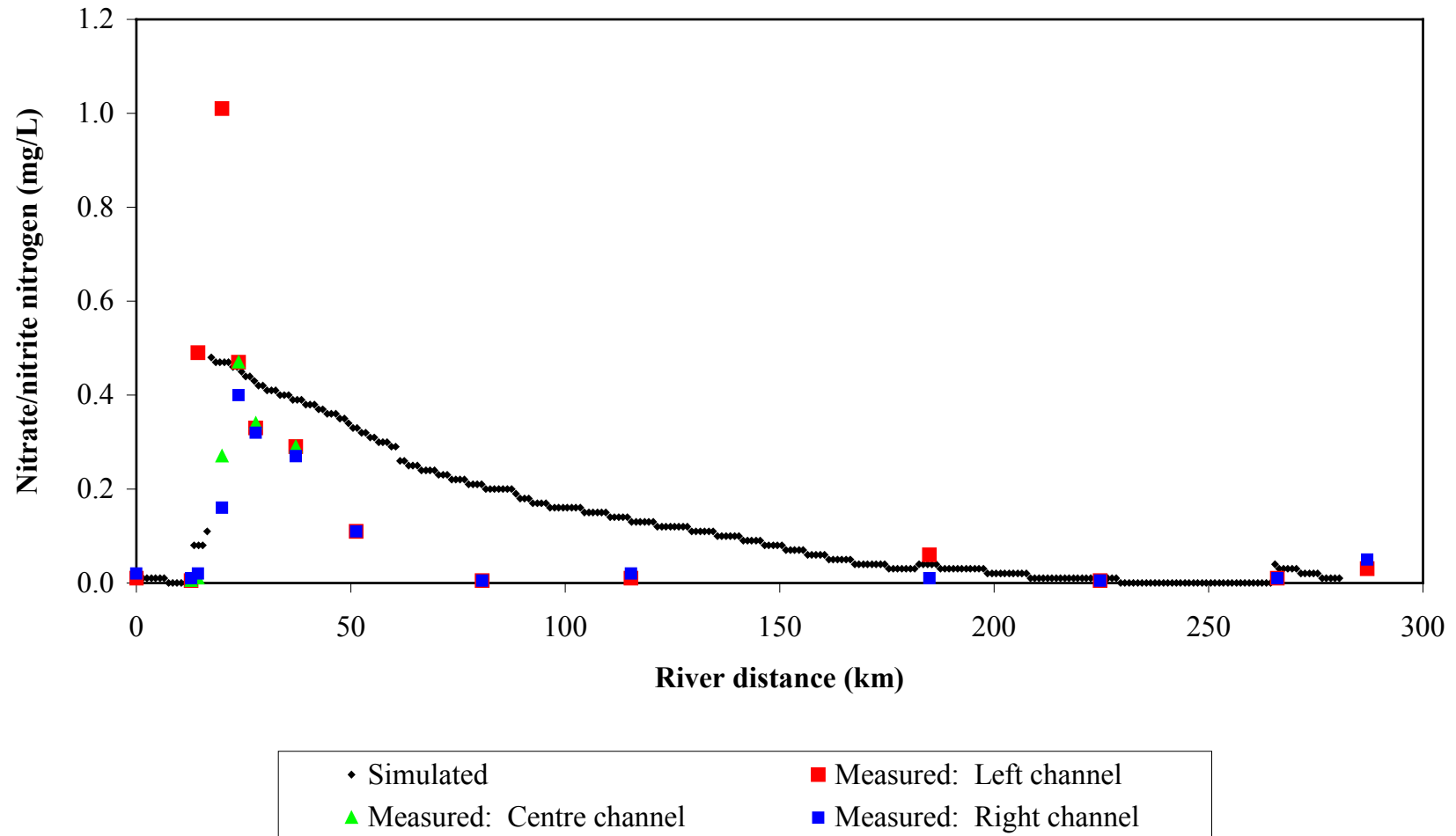


Figure 37. Results of model calibration for nitrate/nitrite, relative to measured concentrations: June 2002.

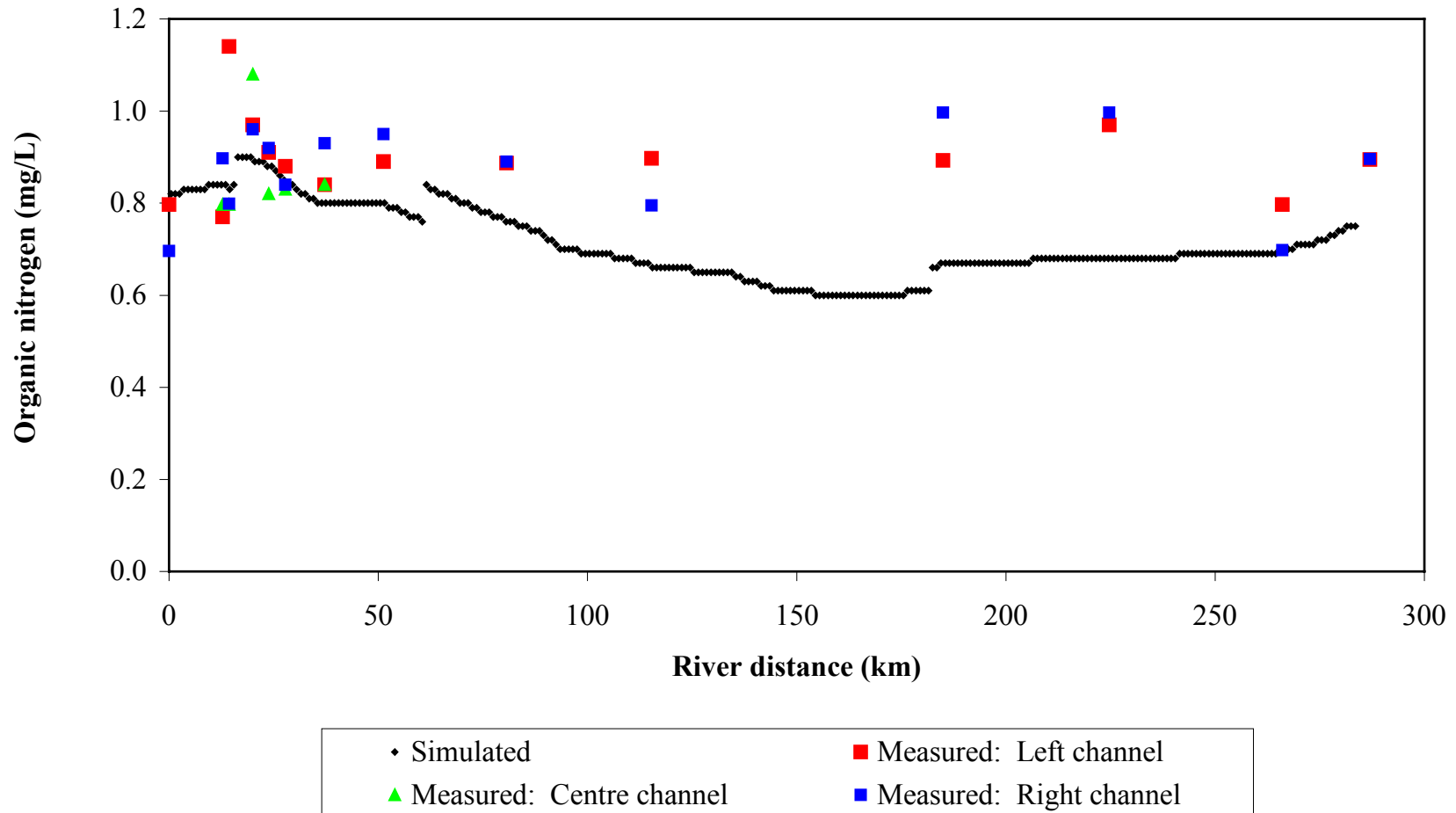


Figure 38. Results of model calibration for organic nitrogen, relative to measured concentrations: June 2002.

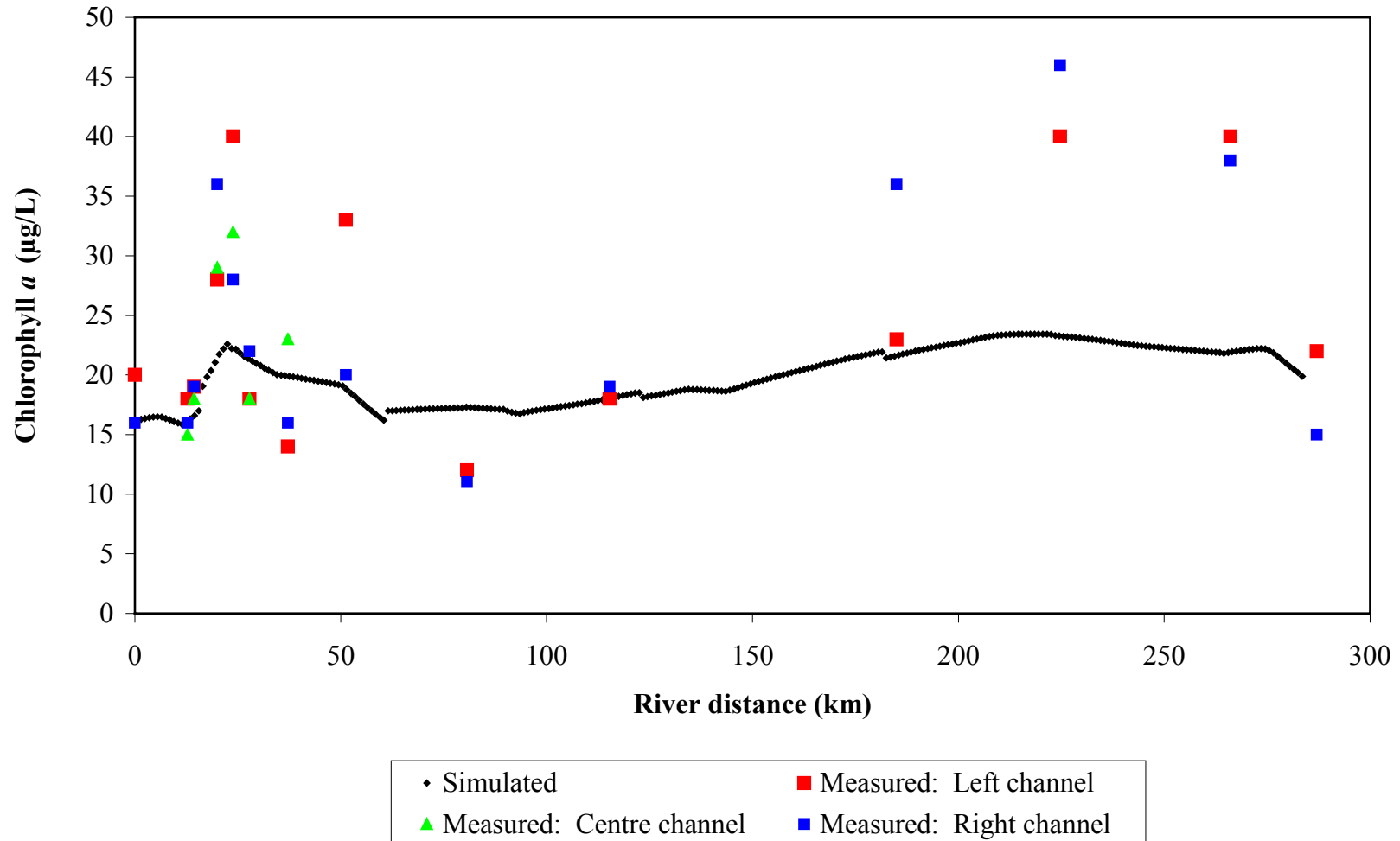


Figure 39. Results of model calibration for chlorophyll *a*, relative to measured concentrations: June 2002.

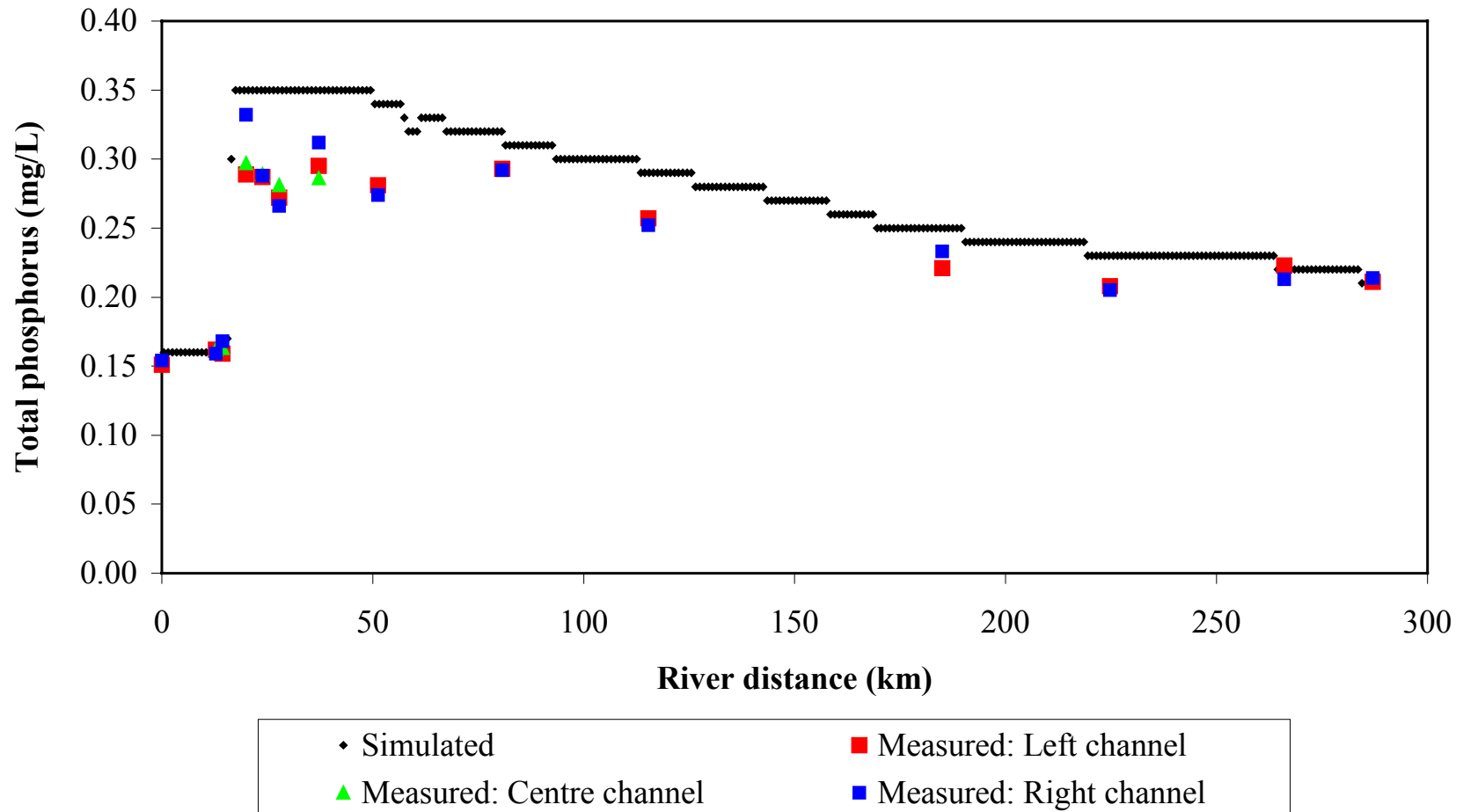


Figure 40. Results of model calibration for total phosphorus, relative to measured concentrations: July 2002.

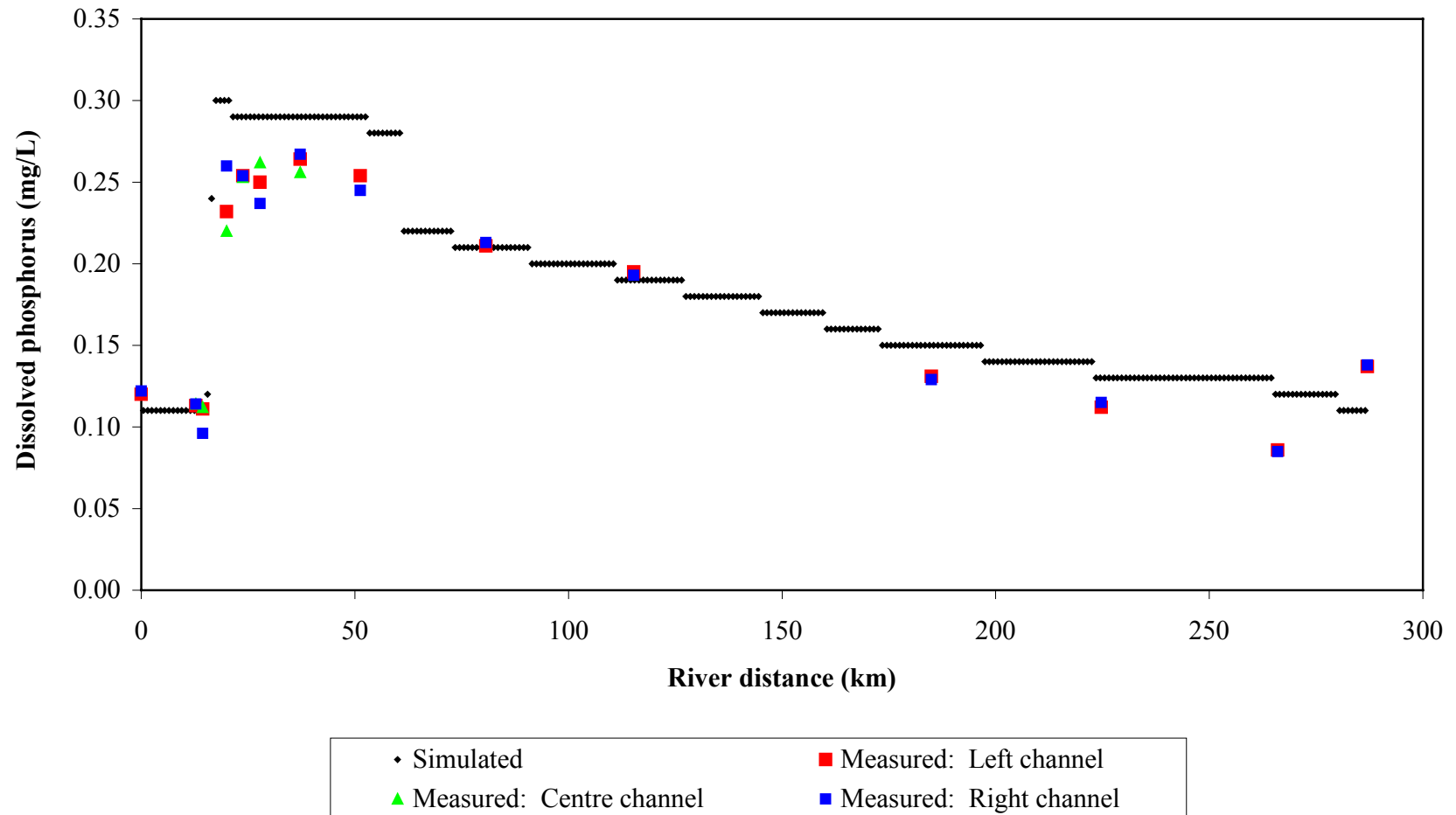


Figure 41. Results of model calibration for dissolved phosphorus, relative to measured concentrations: July 2002.

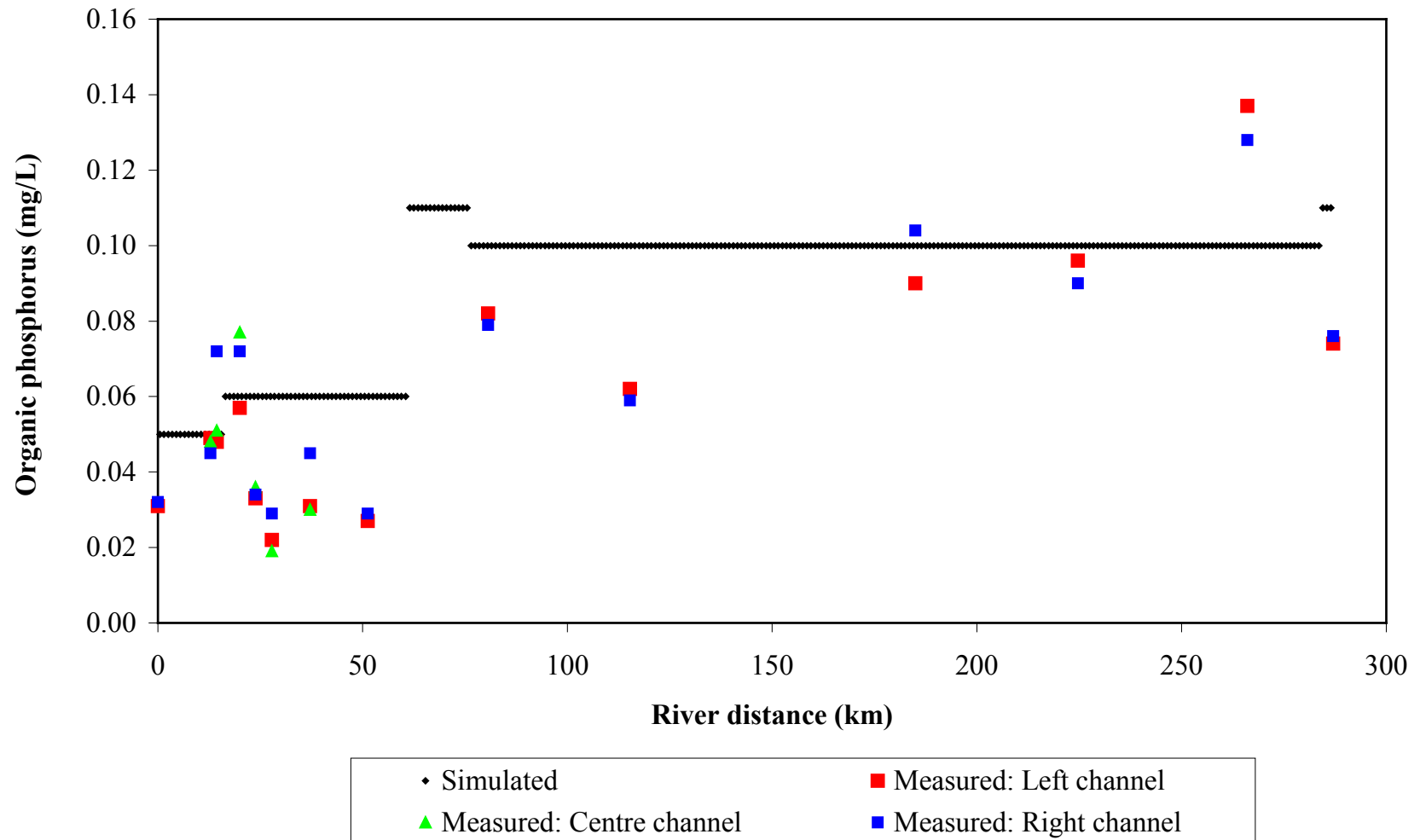


Figure 42. Results of model calibration for organic phosphorus, relative to measured concentrations: July 2002.

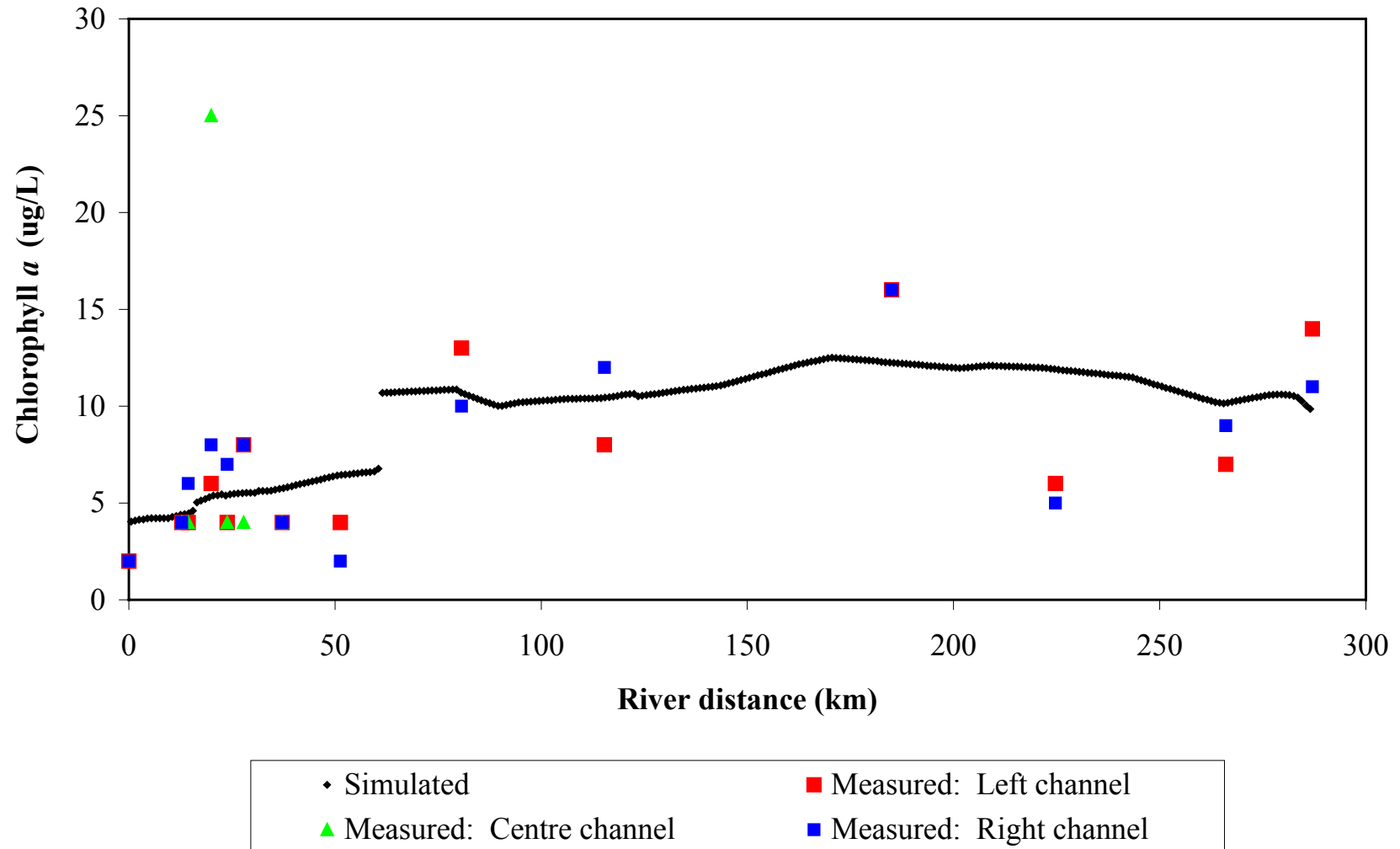


Figure 43. Results of model calibration for chlorophyll *a*, relative to measured concentrations: July 2002.

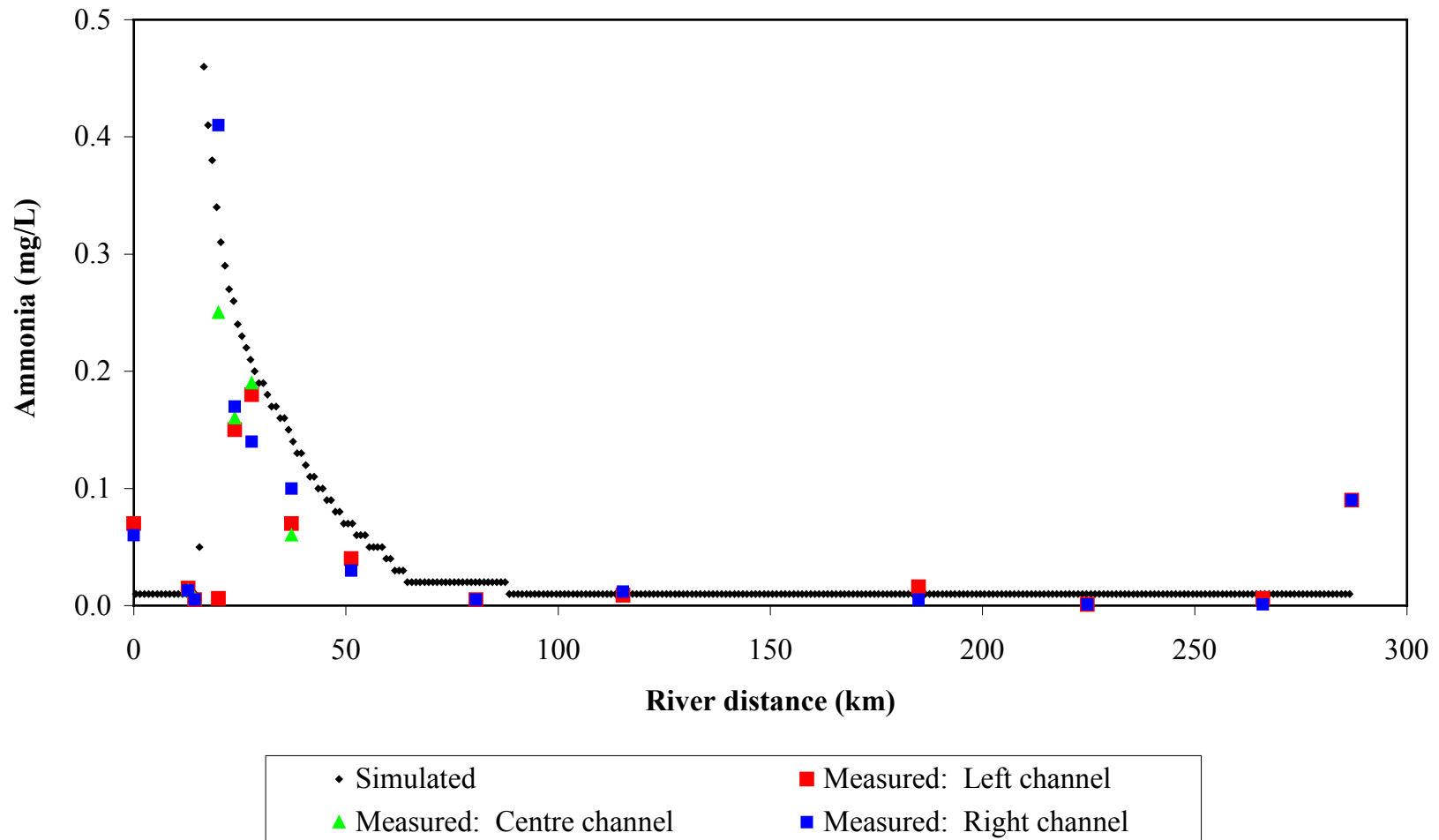


Figure 44. Results of model calibration for ammonia, relative to measured concentrations: July 2002.

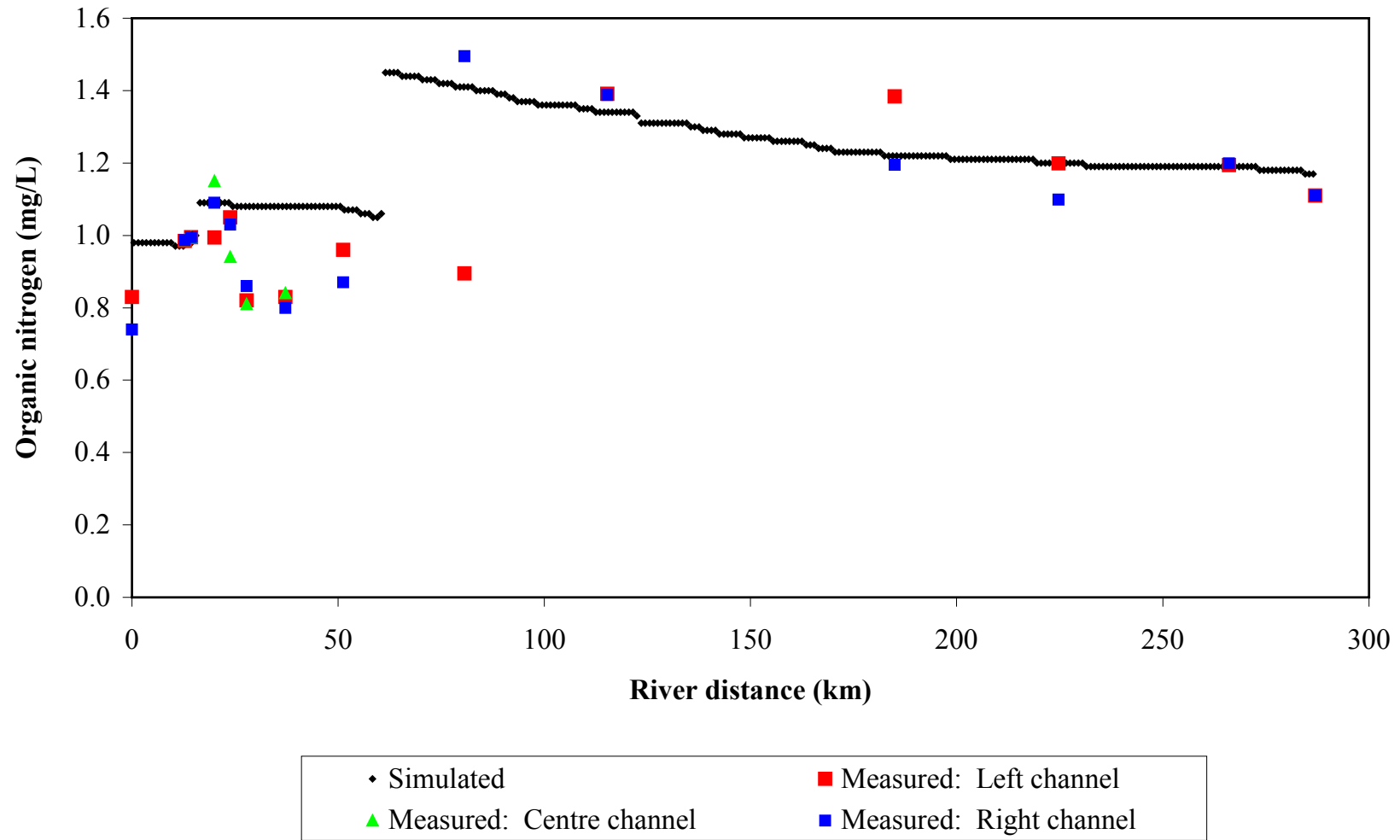


Figure 45. Results of model calibration for organic nitrogen, relative to measured concentrations: July 2002.

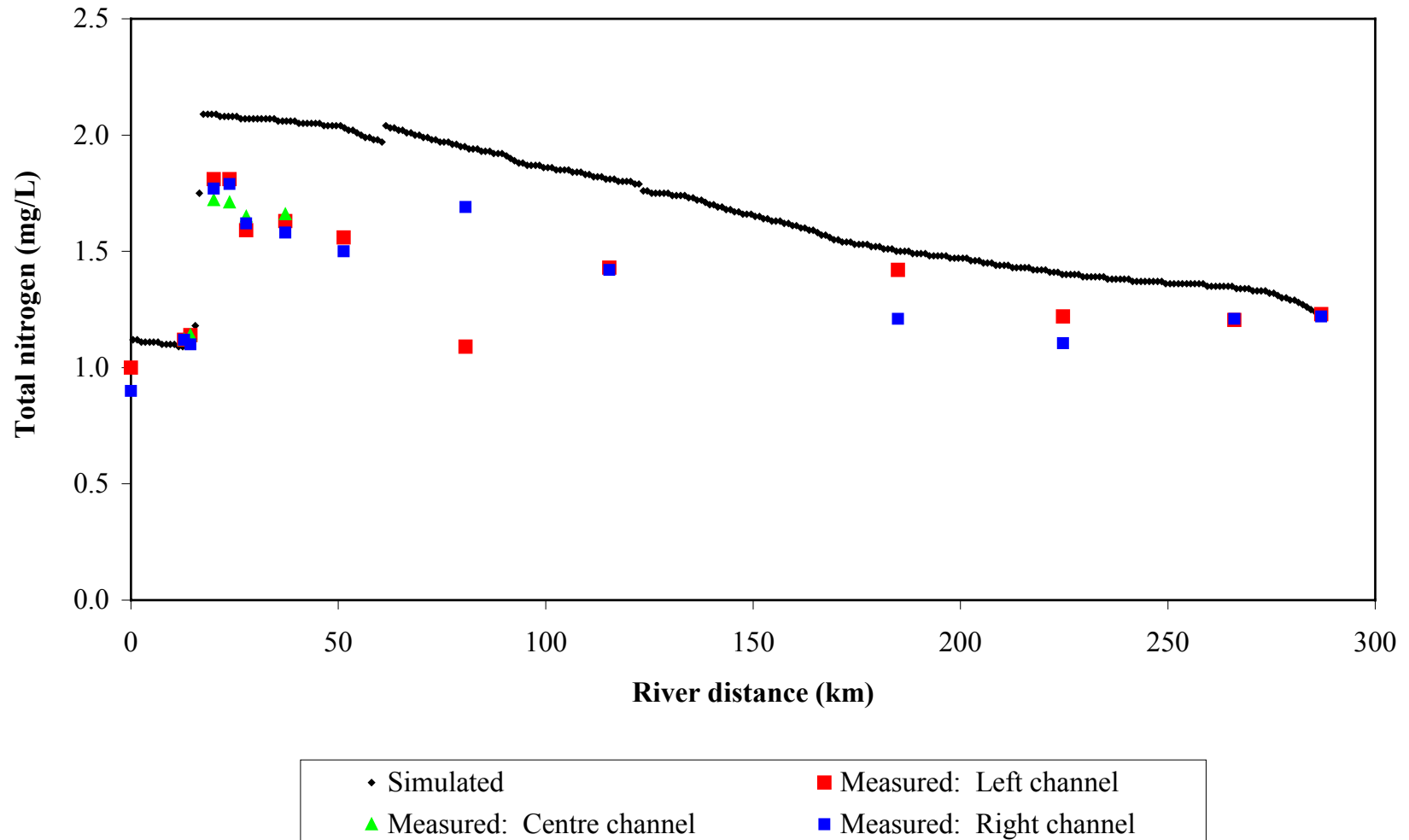


Figure 46. Results of model calibration for total nitrogen, relative to measured concentrations: July 2002.

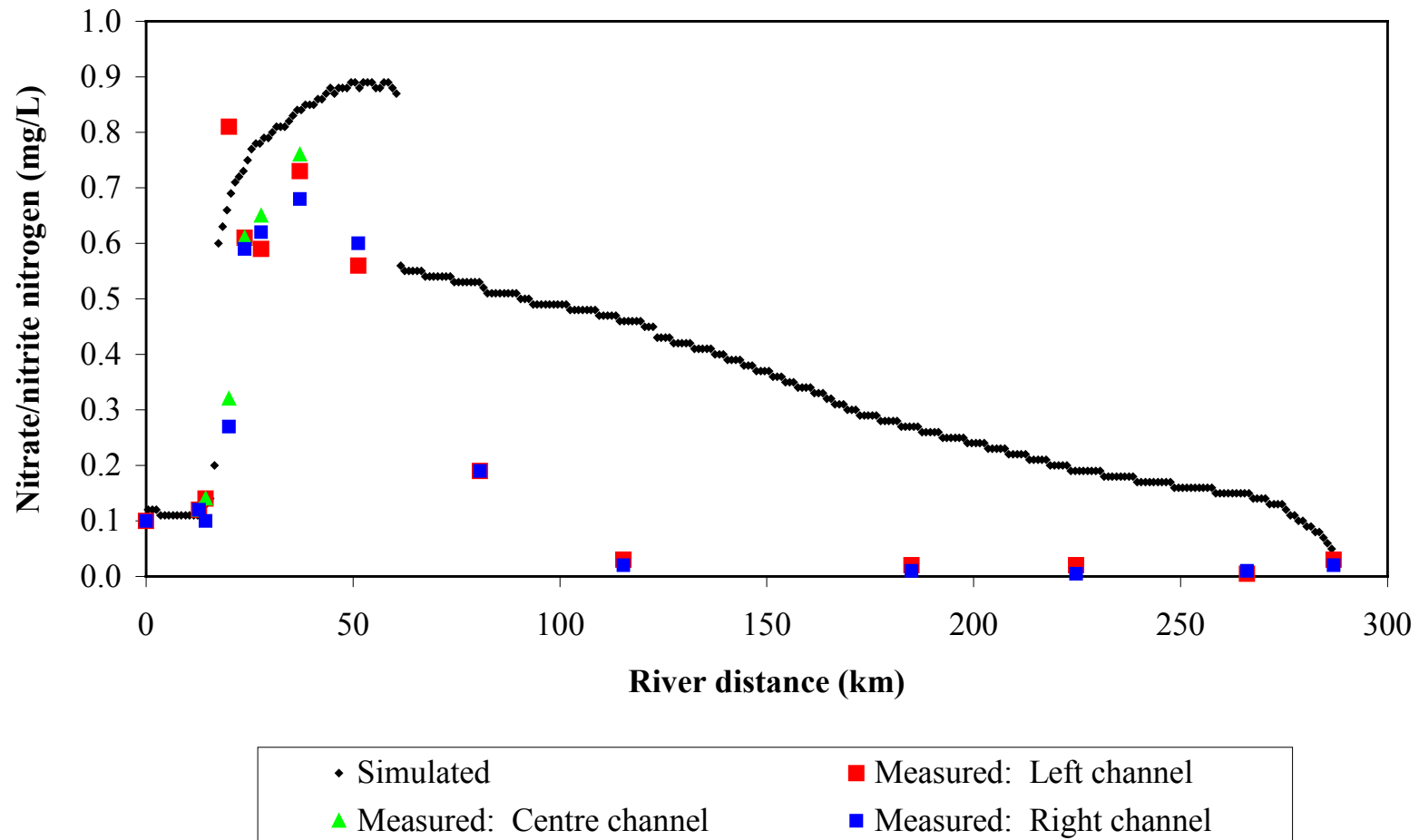


Figure 47. Results of model calibration for nitrate/nitrate, relative to measured concentrations: July 2002.

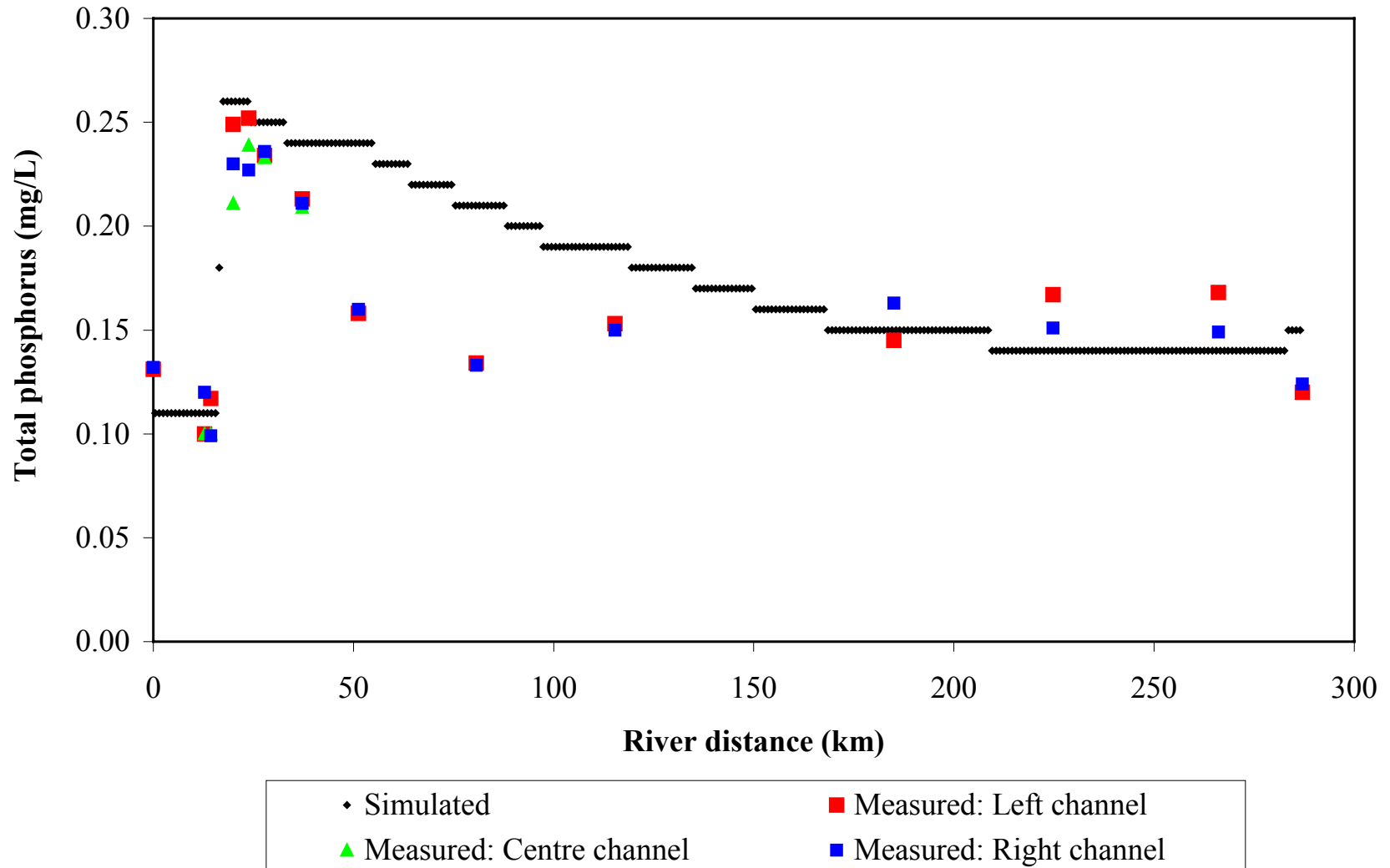


Figure 48. Results of model calibration for total phosphorus, relative to measured concentrations: August/September 2002.

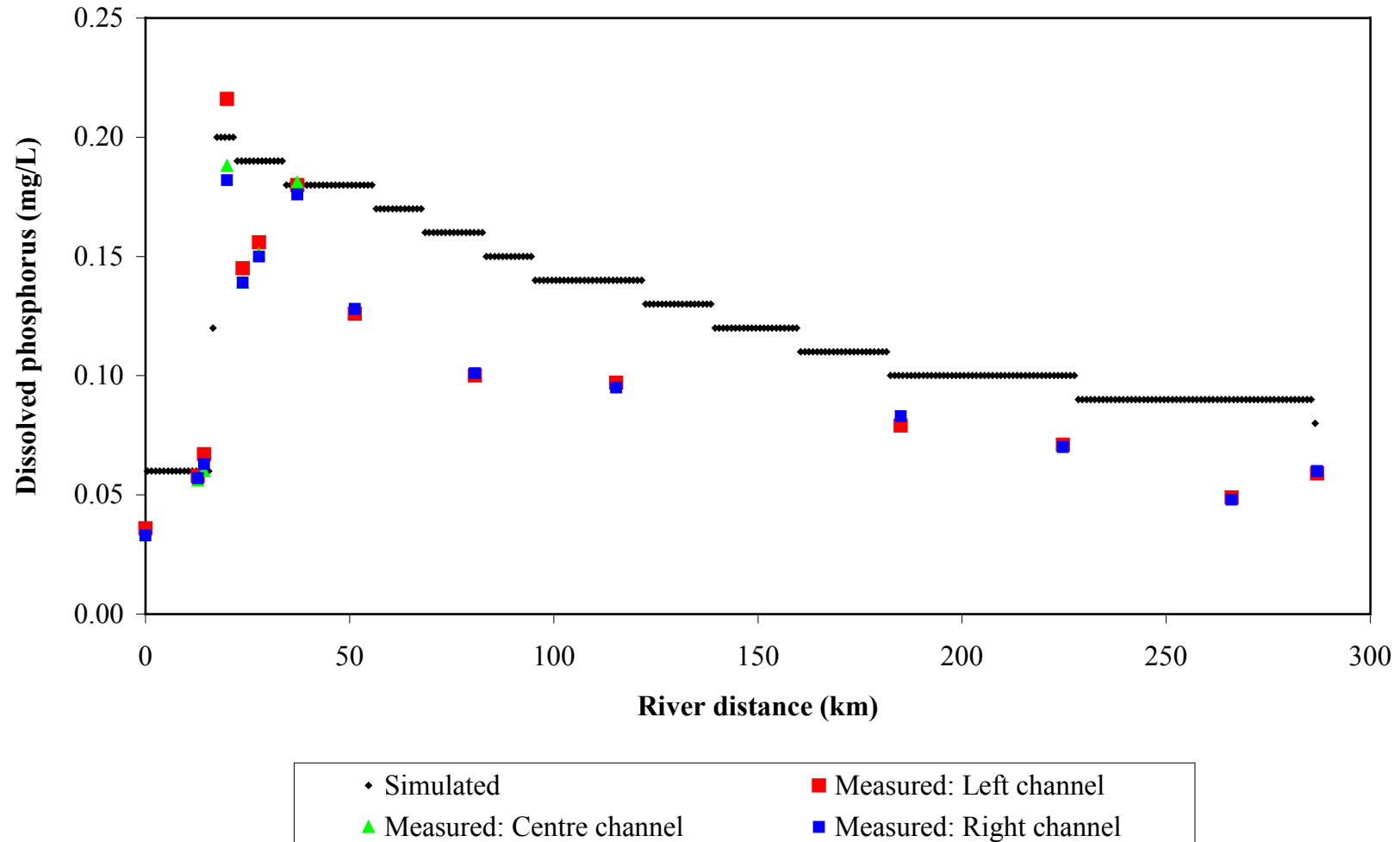


Figure 49. Results of model calibration for dissolved phosphorus, relative to measured concentrations: August/September 2002.

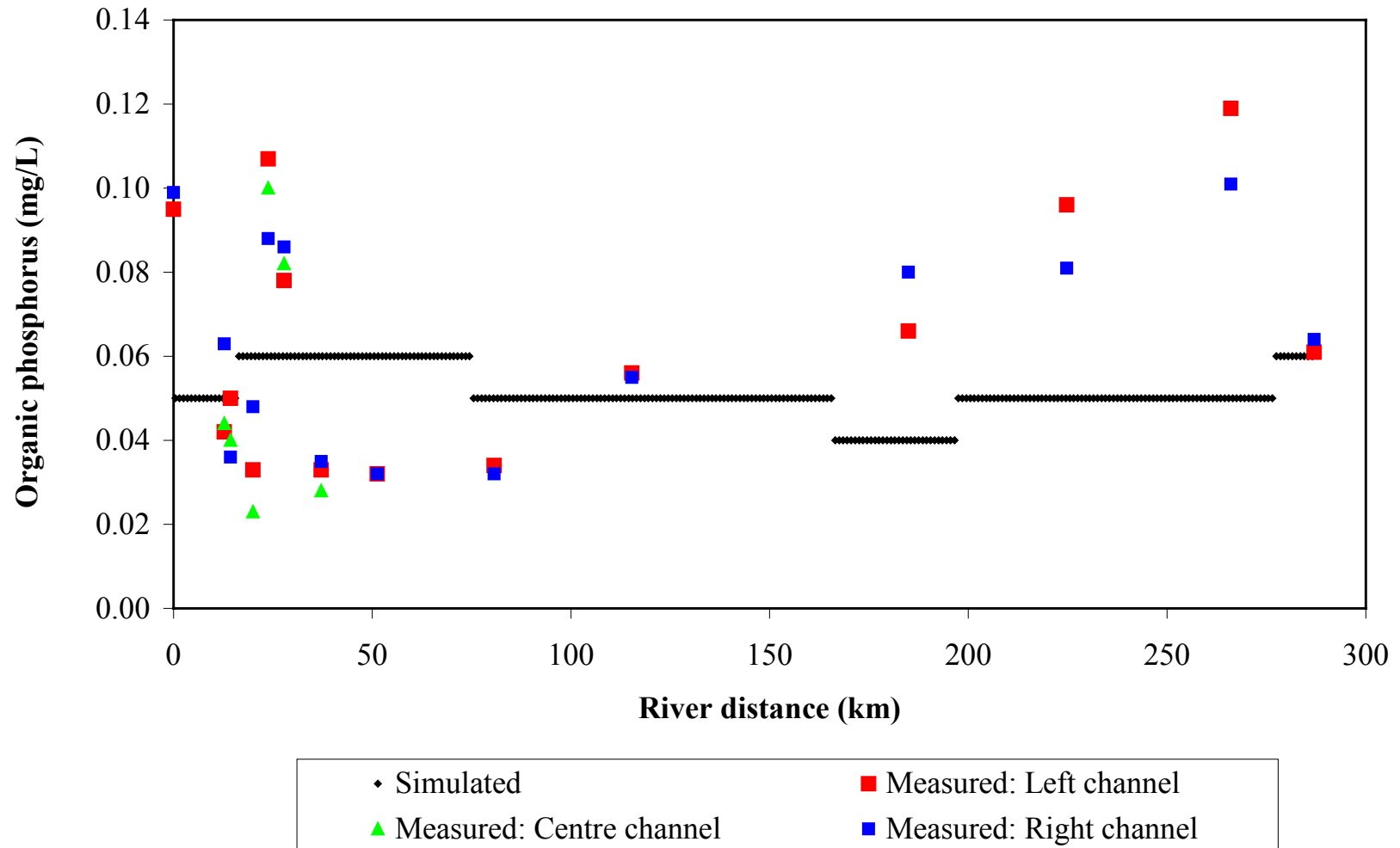


Figure 50. Results of model calibration for organic phosphorus, relative to measured concentrations: August/September 2002.

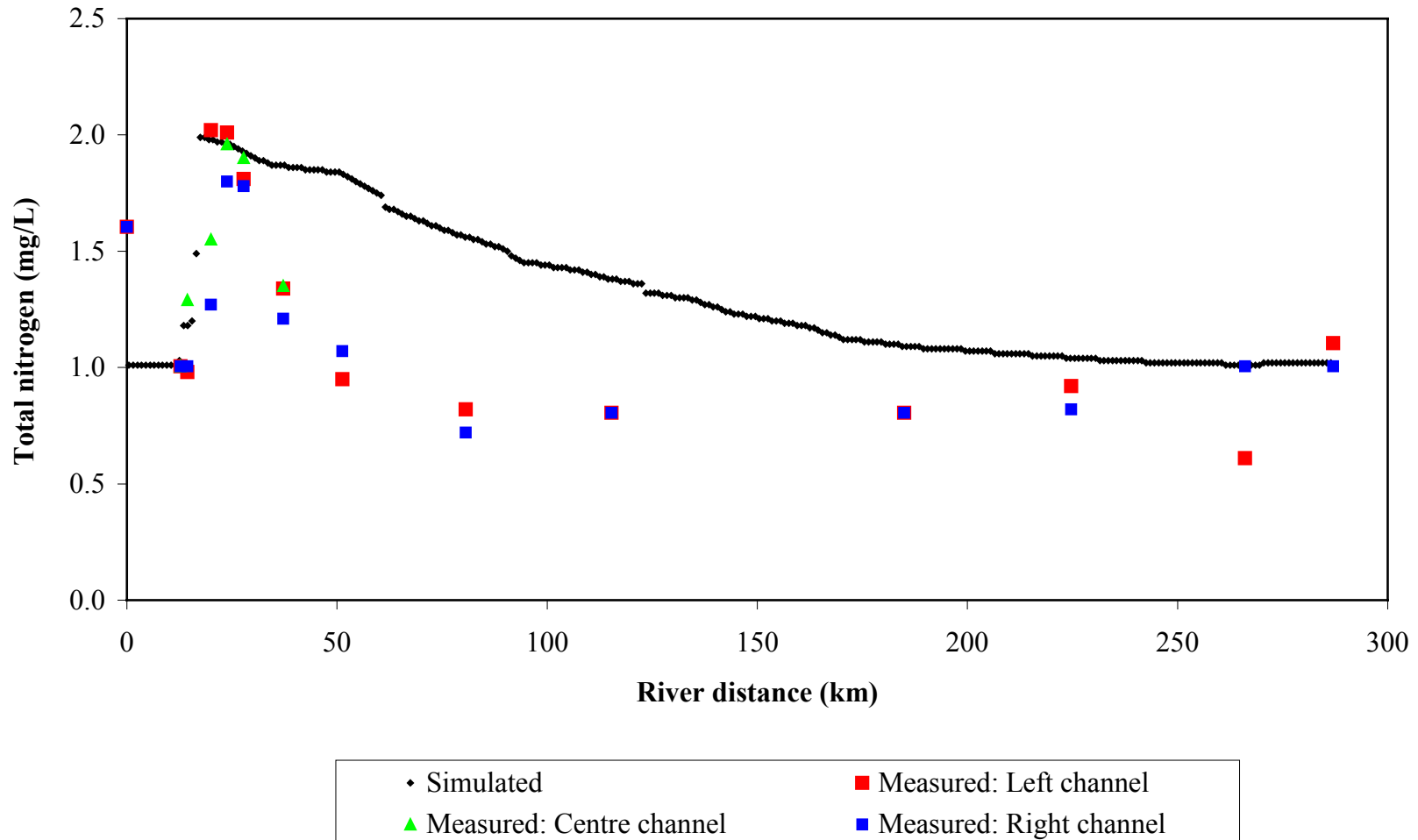


Figure 51. Results of model calibration for total nitrogen, relative to measured concentrations: August/September 2002.

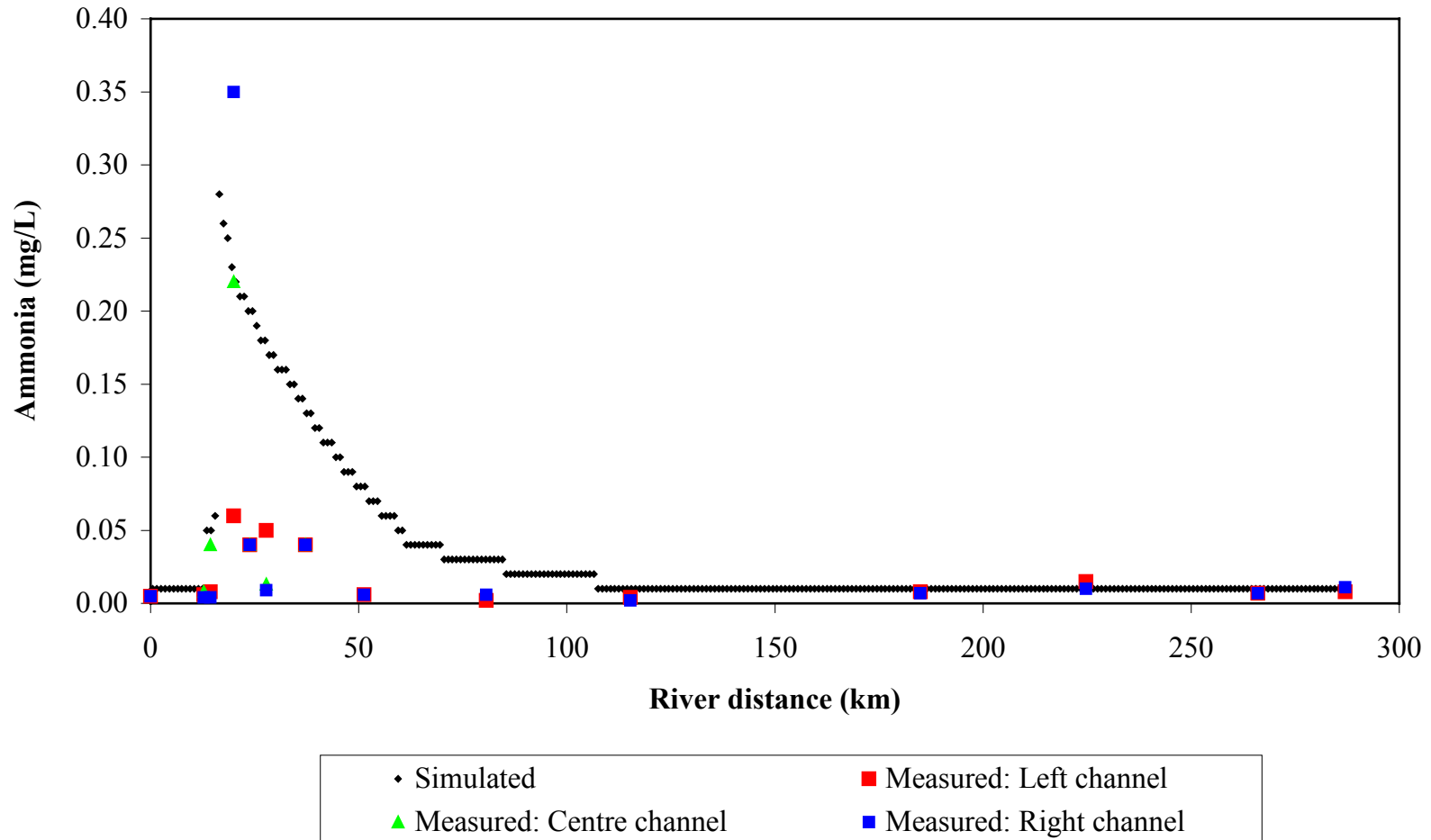


Figure 52. Results of model calibration for ammonia, relative to measured concentrations: August/September 2002.

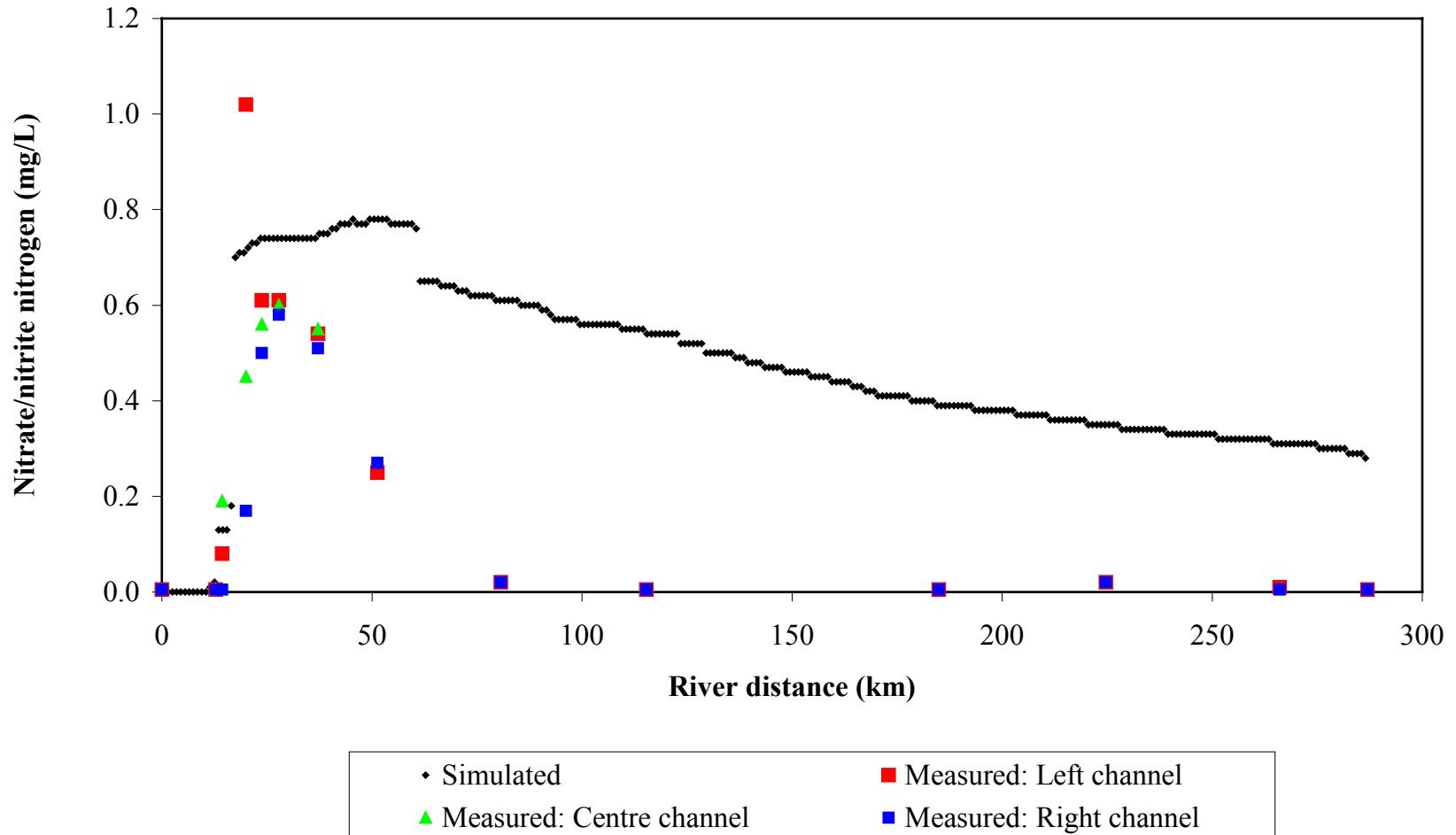


Figure 53. Results of model calibration for nitrate/nitrite, relative to measured concentrations: August/September 2002.

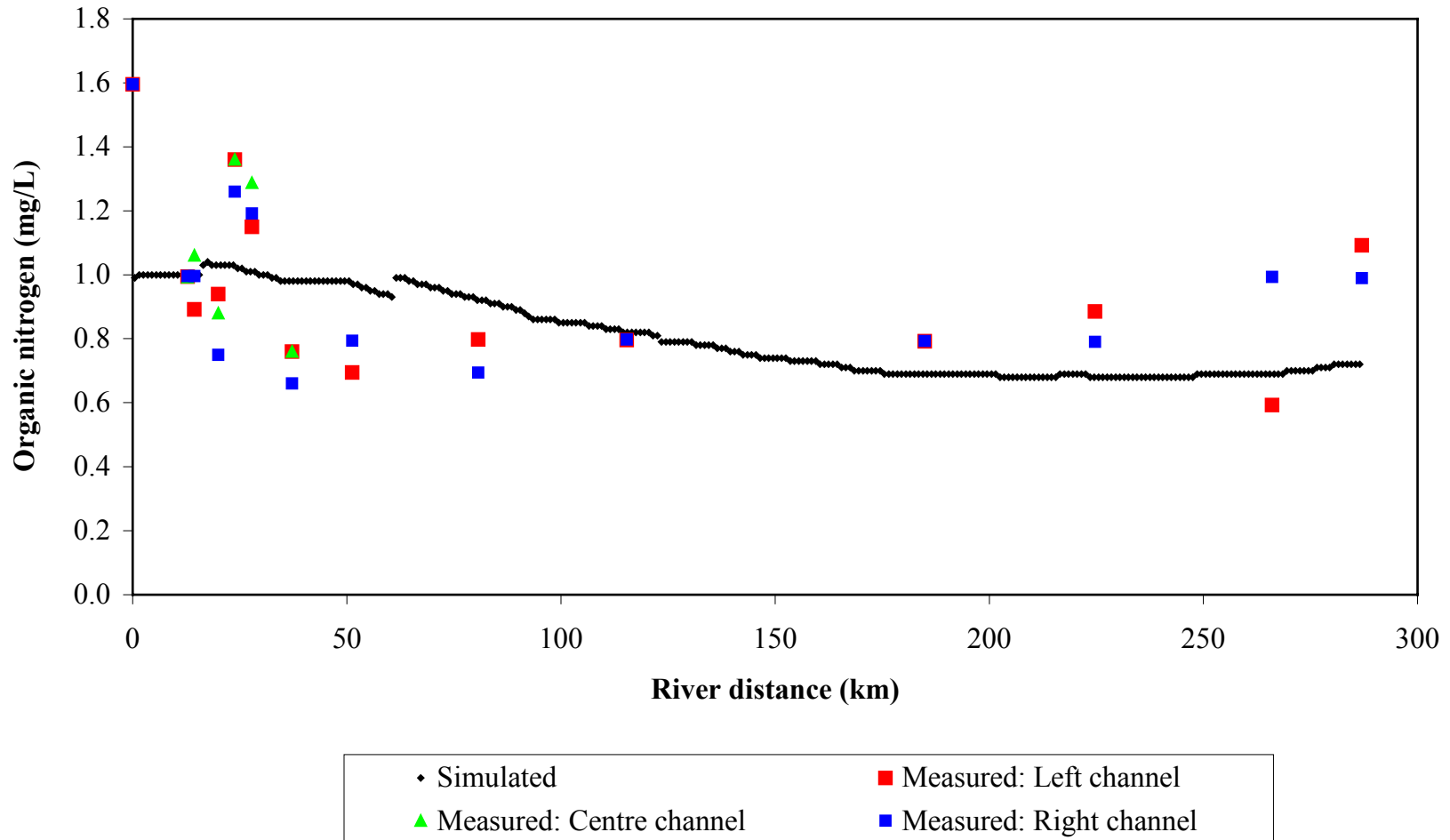


Figure 54. Results of model calibration for organic nitrogen, relative to measured concentrations: August/September 2002.

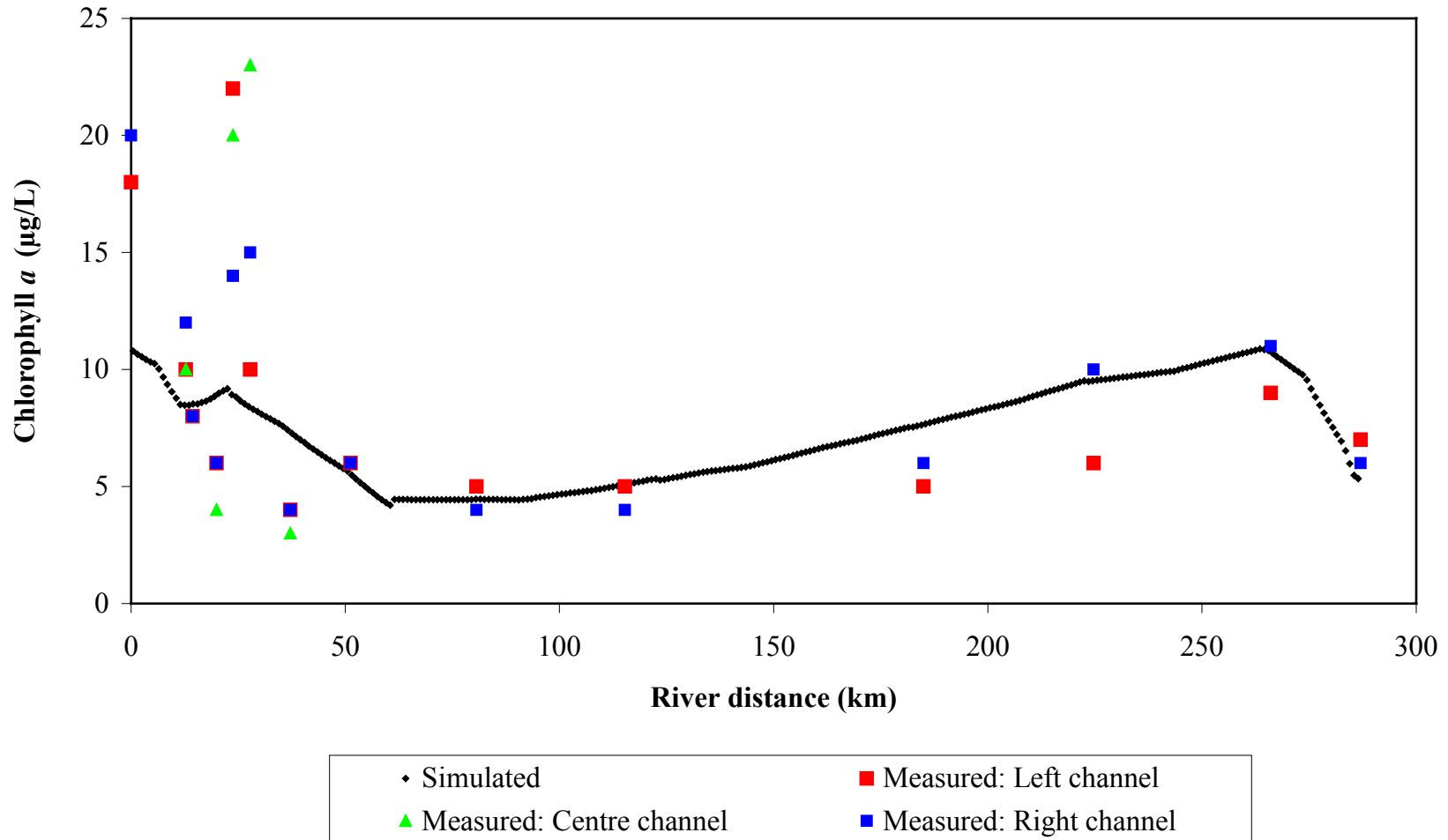


Figure 55. Results of model calibration for chlorophyll *a*, relative to measured concentrations: August/September 2002.

