

Integration of GIS with Hydrologic Model to Determine Water Quality of Dal Lake

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(2014-AE-20-M)



Division of Agricultural Engineering

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**Sher-e-Kashmir University of Agricultural Sciences and
Technology of Kashmir**

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Integration of GIS with Hydrologic Model to Determine Water Quality of Dal Lake

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“Parents”

*Someone who embrace us in arms as we enter this world
Someone who always persuade us with their loving words of praise
Someone who constantly stand by us
Someone who listens tolerantly to all our qualms and stresses
Someone who's eyes shine with pride and contentment at our every little
Achievement*

DEDICATE MY THESIS

To the most beautiful creatures of Allah

**“MY BELOVED PARENTS
(Mrs. & Syed Arshad Hussain Chishti
&
Mrs. & Syed Parvez Ahmad
Hamdani)”**

Sher-e-Kashmir
University of Agricultural Sciences and Technology of Kashmir
Faculty of Horticulture, Division of Agricultural Engineering

Certificate – I

This is to certify that the thesis entitled, **“Integration of GIS with Hydrologic Model to Determine Water Quality of Dal Lake”** submitted in partial fulfillment of the requirements for the award of the degree of **Master of Technology (Soil and Water Engineering)**, to the **Faculty of Horticulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir** is a record of bonafide research work carried out by **Er. ANAUM CHISHTI (Regd. No. 2014-AE-20-M)** under my supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

It is further certified that information received during the course of investigation has duly been acknowledged.

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ABSTRACT

Human interference leads to exploitation of natural resources and the degrading quality of Dal Lake is a live example of effect of human interference to natural resources. The water quality of Dal Lake has deteriorated to a large extent in the past few decades. The main environmental issues being the excessive growth of weeds, high microbial activity and reduction in water clarity. In the present study, one of the models of BASINS (Better Assessment Science Integrating Point and Non-point Sources) i.e. HSPF (Hydrologic Simulation Program-Fortran) was used. HSPF runs in Arc View interface. The main objective of the study was to determine the different pollutant levels coming from various land uses throughout the catchment area by integrating GIS with HSPF. At the end of the study the pH levels from the observed data was found to be range from 6.5-8.5 at all the 3 selected sites. The water temperature at the 3 different sites was found to be in the range of 4-28°C. Dissolved oxygen(DO) was between 5 and 12 mg/l at the surface layer whereas DO levels at lacustrine zone were in the range of 0.5-12 mg/l. TSS ranged between 8-820 mg/l and 0-1000 mg/l in the layer 1 and 6 respectively. Total organic carbon was found to be in the range 2.5-8 mg/l and 2-9 mg/l in layer 1 and lacustrine zone respectively. Particulate organic carbon levels were between 0.2 and 1.8 mg/l and 0 and 1 mg/l for layer 1 and lacustrine zone respectively. Dissolved organic Carbon was found to range between 2.2-5.8 mg/l and 2.1-7 mg/l for layer 1 and lacustrine zone respectively. Ammonia levels ranged between 0.12- 0.3 mg/l and 0-0.5 mg/l for layer 1 and lacustrine zone. The nitrite-nitrate levels ranged from 0.22-0.79 mg/l and 0.28-0.92

mg/l for level 1 and lacustrine zone. The total Phosphorous was found to range between 0.08- 0.23 mg/l and 0.07- 0.32 mg/l for layer 1 and lacustrine zone respectively. The total phosphate (TP) and total organic phosphorous (TOP) for layer 1 was found in the range 0.008-0.023 mg/l and 0.002-0.006 mg/l respectively, whereas the values for TP and TOP for lacustrine zone ranged from 0.009-0.3 mg/l and 0.001-0.009 mg/l.

The simulated values of the nutrients were then compared with the set standard of values by India water portal and the results suggest that the water of the lake is not suitable to be used for drinking, irrigation or domestic purposes, whereas the nutrients are present in adequate quantity for the sustenance of aquatic life. The comparison of land use classes for the year 1991 and 2013 using satellite imagery and ArcGIS shows a decrease of 1.15% in agricultural field, 2.28% in barren land, 5.35% in evergreen forests, 6.5% in orchards and horticulture, 0.41% in open forests, 0.15% in grasslands and meadows and 0.72% in waterbody. However an increase of 7.91% in built up, 2.4% in mixed plantation, 0.62% in recreational park, 1.86% in scrub land and 3.17% in vegetable field was ascertained.

Keywords: Water quality, Dal Lake, BASINS, HSPF, GIS, LULC changes.

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Chapter - 1

INTRODUCTION

General

Future generations inherit the consequences made by its predecessors. Today's actions will certainly impact water quality for future generations. Recent research has revealed that 50-70 per cent of the surface water surveyed was affected by non-point source pollution from soil erosion, sediment, and chemical application (Tim & Jolly 1994). In order to prevent further deterioration, we must establish a method for locating land usage areas that produce the most sediment and result in the highest levels of water pollution. The main focus of water quality models integrated with Geographical Information System (GIS) is to determine the "critical" areas of a watershed so that changes can be made in land use or management practices to alleviate a pollution problem (Edwards *et al.*, 1998).

The greatest degradation impacts to lakes and reservoirs are generally caused by human activities in their surrounding drainage basins. World's urban population has increased 15 times from 200 million in 1900 to about 2.9 billion in 2000, and is projected to reach 9.7 billion by 2050. The current world population of 7.3 billion is expected to reach 8.5 billion by 2030, 9.7 billion in 2050 and 11.2 billion in 2100 (UN, 2015).

The Dal Lake is not only an important spot for the tourism industry of the valley but is an important aspect of the environmental and ecological aspects of the city of Srinagar. Since the already prevailing management practices are not that effective in helping to curb the deterioration of the waters of the Dal Lake therefore, it is very important to change some of the ongoing practices in order to help in the betterment of the water quality of the lake.

With the help of this proposed research we can predict the water quality of the lake and can also devise better management practices around the vicinity of the lake in order to help curb the point and non-point source pollution of the lake. The present pH of Dal Lake is 6.4-8.7, Nitrates are in the range of 0-0.7 mg/l, Phosphates are in the range of 0.03-0.11 mg/l and TSS are in the range of 220-850

mg/l [Source: Lakes and Waterways Development Authority (LAWDA), Kashmir, 2014].

The study area was selected for change detection because of being subjected to unplanned urbanization, soil erosion, deforestation and changes in land use practices.

The rapid urban development in the catchment area of Dal Lake has led to environmental problems. With Dal Lake being a fragile ecosystem the unplanned urbanization and human interference in the catchment area has resulted in water pollution and fragmentation of aquatic habitats (Malik and Ali, 2012).

GIS technology has played critical roles in all aspects of watershed management, from assessing watershed conditions through modeling impacts of human activities on water quality and to visualizing impacts of alternative management scenarios (Chebet, 2012). The field and science of GIS have been transformed over the last two decades. Advancements in computer hardware and software, availability of large volumes of digital data, the standardization of GIS formats and languages, the increasing interoperability of software environments, the sophistication of geo-processing functions, and the increasing use of real-time analysis and mapping on the internet have increased the utility and demands for the GIS technology. In turn, GIS application in watershed management has changed from operational support to prescriptive modeling and tactical or strategic decision support system. Increasingly, researchers, resource planners and policy makers are realizing the power of GIS and its unique ability to enhance watershed management (Tim and Sumant, 2003).

The most fundamental human needs for water are for drinking, cooking and personal hygiene. To meet these needs, the quality of the water used must pose no risk to human health. The quality of the water in nature also affects the condition of ecosystems that all living organisms depend on. At the same time, humans use water bodies as convenient sinks for the disposal of domestic, industrial and agricultural waste waters. This of course degrades the quality of those water bodies. Water resources management involves the monitoring and management of water quality as much as the monitoring and management of

water quantity. Various models have been developed to assist in predicting the water quality impacts of alternative land and water management policies and practices (Biswas, 2004).

Water quality management is a critical component of overall integrated water resources management. As populations and economies grow, more pollutants are generated. Many of these are waterborne, and hence can end up in surface and groundwater bodies. Increasingly, the major efforts and costs involved in water management are devoted to water quality protection and management. Conflicts among various users of water are increasingly over issues involving water quality as well as water quantity. Natural water bodies are able to serve many uses, including the transport and assimilation of water-borne wastes. But as natural water bodies assimilate these wastes, their quality changes. If the quality drops to the extent that other beneficial uses are adversely affected, the assimilative capacities of those water bodies have been exceeded with respect to those affected uses. Water quality management measures are actions taken to ensure that the total pollutant loads discharged into receiving water bodies do not exceed the ability of those water bodies to assimilate those loads while maintaining the levels of quality specified by quality standards set for those waters (Edwards *et al.*, 1998).

Modeling can be used to assess (predict) future water quality situations resulting from different management strategies. Combined runoff and water quality prediction models link stressors (sources of pollutants and pollution) to responses. Stressors include human activities likely to cause impairment, such as the presence of impervious surfaces in a watershed, cultivation of fields close to the stream, excessive irrigation of crops with resulting polluted return flows, the discharge of domestic and industrial effluents into water bodies, installing dams and other channelization works, introduction of non-indigenous taxa and over-harvesting of fish. Indirect effects of humans include land cover changes that alter the rates of delivery of water, pollutants and sediment to water bodies (Shi *et al.*, 2012).

“Land cover” refers to the vegetative or non-vegetative characteristics of a portion of the Earth’s surface. “Land use” describes some human activity on the surface. The concept of land cover is best understood when applied to natural surfaces where no activity has occurred (e.g., unharvested forest land). The type of land cover present is determined directly by observation. This observation may use satellite imagery or aerial photography for certain levels of classification detail and positional accuracy. It has been noted that as the scale of mapping increases (more detailed mapping), applications using a map become more dependent on land use information. While the difference between land use and land cover is not always obvious in specific instances, a fundamental distinction does exist.

Dal lake is a very sensitive and ecologically as well as economically important aspect of the city of Srinagar. The unplanned urbanization and deforestation and the change of land use practices has increased the pressure on the lake thereby leading to the deterioration of the water quality of the lake. This study will help in determining the water quality of Dal lake using HSPF and thus will help in determining the management strategies that can be implemented for helping in the betterment of the water quality of the lake and can help in restoring the lost glory of the lake.

Keeping the above points in view the study entitled “Integration of hydrologic model to determine water quality of Dal Lake” was undertaken to determine the water quality of Dal Lake using hydrologic model with GIS and also determination of changes occurred in land use land cover for the last 2 decades. The main objectives of the study were:

- To predict water quality using HSPF (Hydrological Simulation Program- Fortran.)
- Analysis of the determined values of water quality with the set standards for use of water for irrigation and domestic purposes.
- Integration of GIS with hydrological simulation model (HSPF) to determine the management strategies around the catchment area of Dal Lake.

Chapter - 2

REVIEW OF LITERATURE

2.1 Water quality of Dal Lake

The demand for water and land resources expands with the increase of human activities in many regions, resulting in ecological & environmental concerns (Singh *et al.*, 2005). The valley of Kashmir located in the northern Indian Himalayas, is represented by breathtaking lakes, mountains, snow and spring-fed streams, finest meadows & alpine forests.

In Kashmir valley the eutrophication and dwindling of the lake ecosystems is a very recent event of the past 10-30 years, coinciding with a marked civilization evolution in the lake drainage basins (Pandit, 1998). Since there has not been much industrial development in the Kashmir valley, the main contributors towards the degradation of these water bodies are land use changes, unplanned urbanization, increased soil erosion & reckless use of pesticides in the catchment areas (Badar and Romshoo, 2008).

Wani *et al.* (1996) analyzed data from Indian Remote Sensing satellite (IRS)-1B and spectral data from Linear Imaging Self Scanner LISS-II to determine the feasibility of quantifying the concentration of suspended solids in the surface water of inland water body, Dal Lake, in Srinagar, India. The water samples collected in concurrence with IRS-1B over-pass, were analyzed to determine the concentration of suspended solids. The results indicate that a positive functional relationship exist between the concentration of suspended solids and the visible wave length bands 1 and 3 and near infrared band 4. It has been observed that as the concentration of suspended solids increase, the spectral response also increases. It is concluded that IRS LISS-II data can be effectively used to quantify suspended sediment concentration in the Dal lake surface water.

Jeelani and Shah (2006) have analyzed 240 water samples (in 4 seasons) and 17 sediment samples to monitor the natural and anthropogenic influences on the water and sediment chemistry of the Dal Lake, Kashmir Himalayas. The scatter diagrams $[(Ca+Mg)/total\ cations\ (TZ^+)]$, $(Ca+Mg)/HCO_3$, $(Ca+Mg)/$

(HCO_3+SO_4), $(\text{Na}+\text{K})/\text{TZ}^+$; $(\text{Ca}+\text{Mg})/(\text{Na}+\text{K})$] and the geological map of the study area suggest predominance of carbonate and silicate weathering. Lower pH and high total dissolved solids, electrical conductivity and $\text{NO}_2\text{--NO}_3$ values in the Gagribal basin and in some patches of other basins reflect anthropogenic inputs in the form of sewage from surrounding population, houseboats, hotels, etc. The Dal Lake is characterized by high chemical index of alteration, reflecting extreme weathering of the catchment area. Relative to the average carbonates, the lakebed sediments are enriched in Al, Ti, Zn, Cu and Co and depleted in Ni and Mn. Compared to the post-Archean Shale the sediments have higher Al, Zn and Cu contents and lower Ni and Co. There are distinct positive anomalies of Al, Mn, Zn and Cu and negative anomalies of Ni and Pb with respect to the upper continental crust. Geoaccumulation index (I_{geo}) and the US Environmental Protection Agency sediment quality standards indicate that the Gagribal basin and some patches of the Nagin basin are polluted with respect to Zn, Cu and Pb. These data suggest that the Dal Lake is characterized by differential natural and anthropogenic influences.

Najar and Khan (2012) applied multivariate statistical techniques, such as cluster analysis, principal component analysis (PCA) and factor analysis (FA) to evaluate and interpret the water quality data set for 13 parameters at 10 different sites of the three lakes in Kashmir, India. Physiochemical parameters varied significantly ($p < 0.05$) among the sampling sites. Hierarchical cluster analysis grouped 10 sampling sites into three clusters of less polluted, moderately polluted and highly polluted sites, based on similarity of water quality characteristics. FA/PCA applied to data sets resulted in three principal components accounting for a cumulative variance of 69.84, 65.05 and 71.76% for Anchar Lake, Khushalsar Lake and Dal Lake, respectively. Factor analysis obtained from principal components (PCs) indicated that factors responsible for accelerated eutrophication of the three lakes are domestic waste waters, agricultural runoff and to some extent catchment geology. This study assesses water quality of three lakes through multivariate statistical analysis of data sets for effective management of these lakes.

2.2 Integration of GIS with hydrologic models

Donigian, and Huber (1991), reviewed and discussed non-point source assessment procedures and modeling techniques for both urban and non-urban land areas. Detailed reviews of specific methodologies and models were presented, along with overview discussions focusing on urban methods and models, and on non-urban (primarily agricultural) methods and models. Simple procedures, such as constant concentration, regression, statistical and loading function approaches were described, along with complex models such as SWMM, HSPF, STORM, CREAMS, SWRRB, and others. Brief case studies of ongoing and recently completed modeling efforts were described. Recommendations for nonpoint runoff quality modeling were presented to elucidate expected directions of future modeling efforts.

Edwards *et al.* (1998) used Hydrologic Unit/Water Quality (HU/WQ) tool which provides an intermediate integration between AGNPS (Agricultural Non-Point Source Pollution & GRASS (Geographic Resource Analysis Support System). The overall purpose of this study was to evaluate the use of this software as an aide in modeling water quality for Fort Gordon, Augusta, which would predict the effects to water quality produced by changes in land use as well as predict impacts of existing land use condition to the quality of water on & leaving the area.

Bhaduri *et al.* (2000) applied a long term hydrologic impact assessment (L-THIA) model to the Little Eagle Creek (LEC) watershed near Indianapolis, Indiana, USA. Historical land-use scenarios for 1973, 1984, and 1991 were analyzed to track land-use change in the watershed and to assess impacts on annual average runoff and Non-Point Source (NPS) pollution from the watershed and its five sub-basins. For the entire watershed between 1973 and 1991, an 18% increase in urban or impervious areas resulted in an estimated 80% increase in annual average runoff volume and estimated increases of more than 50% in annual average loads for lead, copper, and zinc. Estimated nutrient (nitrogen and phosphorus) loads decreased by 15% mainly because of loss of agricultural areas. The L-THIA/NPS GIS model is a powerful tool for identifying environmentally

sensitive areas in terms of NPS pollution potential and for evaluating alternative land use scenarios for NPS pollution management.

Jain *et al.* (2001) used two different soil erosion models, i.e. the Morgan model and the Universal Soil Loss Equation (USLE) model, to estimate soil erosion from a Himalayan watershed. Parameters required for both models were generated using remote sensing and ancillary data in GIS mode. The soil erosion estimated by Morgan model is in the order of 2200 sq.km/yr and is within the limits reported for this region. The soil erosion estimated by USLE gives a higher rate. Therefore, for the present study the Morgan model gives, for area located in hilly terrain, fairly good results.

Badar and Romshoo (2008) have used one of the models of BASINS i.e. PLOAD (pollution load). The main objective of the study was to define pollutant levels coming from various land uses throughout the catchment into the lake & using modeling to assess the effect of various management alternatives (land use changes) on water quality & to provide a technically sound tool to assess the current & future water quality conditions.

Romshoo and Muslim (2011) have used remote sensing, simulation modeling and field observations to assess the non-point source pollution load of a Himalayan lake from its catchment. The GIS-based distributed modeling approach employed relied on the use of geospatial data sets for simulating runoff, sediment, and nutrient (N and P) loadings from a watershed, given variable-size source areas, on a continuous basis using daily time steps for weather data and water balance calculations. The model simulations showed that the highest amount of nutrient loadings are observed during wet season in the month of March (905.65 kg of dissolved N, 10 kg of dissolved P, 10,386.81 kg of total N and 2,381.89 kg of total P). The 11-year simulations (1994-2004) showed that the main source areas of nutrient pollution are agriculture lands and wastelands. On an average basis, the source areas generated about 3,969.66 kg/year of total nitrogen and 817.25 kg/year of total phosphorous. Nash-Sutcliffe coefficients of correlation between the daily observed and predicted nutrient load ranged in value from 0.80 to 0.91 for both nitrogen and phosphorus.

Shi *et al.* (2012) calculated the discharge of total nitrogen and phosphorus in Wuliangshuai watershed by using the pollutant load estimator (PLOAD) model. Fifty-nine watersheds were divided, among which thirty-three watersheds with higher agriculture land percentage (above 50%) were targeted for Best Management Practices (BMPs), as the pollutant load is heavier in agricultural land than in any other types of land use in Wuliangshuai watershed. Scenarios of the total NPS pollutant emission with or without agricultural BMPs were calculated and compared by using the PLOAD model. The results indicated that the emissions of total nitrogen and total phosphorus could be reduced by 54.68% and 41.54%, respectively, which means agricultural BMPs is a rational option for watershed restoration. The result could provide technical support and scientific reference for the protection of aquatic environment and for the formulation of conservation policy in Wuliangshuai watershed.

2.3 Hydrologic Simulation Program- Fortran (HSPF) and Geographic Information System (GIS)

Al-Abed and Whiteley (2002) described calibration procedures for water quality parameters of the HSPF version 10.11 using the automatic-calibration parameter estimator model coupled with a geographical information system (GIS) approach for spatially averaged properties. Calibration efforts were directed to those model parameters that produced large changes in model response during sensitivity tests run prior to undertaking calibration. A GIS was used extensively in this study. It was first used in the watershed segmentation process. During calibration, the GIS data were used to establish realistic starting values for the surface and subsurface zone parameters and physically reasonable ratios of these parameters among watersheds were preserved during calibration with the ratios based on the known properties of the sub-watersheds determined using GIS. This calibration procedure produced very satisfactory results; the percentage difference between the simulated and the measured yearly discharge ranged between 4 to 16%, which is classified as good to very good calibration. The average simulated daily discharge for the watershed outlet at Brantford for the years 1981-85 was 67 cumec and the average measured discharge at Brantford was 70 cumec. The coupling of a GIS with automatic calibration produced a realistic and accurate

calibration for the HSPF model with much less effort and subjectivity than would be required for unassisted calibration.

Albek *et al.* (2004) used HSPF for hydrological modeling in the Middle Seydi Suyu Watershed, Turkey for the years 1991-1994. The model was calibrated using the data from 1991-1993 and validated with data for the year 1994. The effects of an increase in temperature due to climate change, and the effects of maximum and minimum watershed cover modifications were examined. The results indicated that an annual mean temperature increase of 3 °C due to climate change will decrease the watershed outflows by 21%. The existence of the deep rooted vegetation covering the whole of the watershed was observed to cause a decrease in the total stream outflow by 37% compared to base model results. In the case of no deep rooted vegetation the total stream outflow increased by 40% compared to the current vegetation distribution.

Singh *et al.* (2005) used watershed scale hydrologic simulation models HSPF (Hydrologic Simulation Program- Fortran) and SWAT (Soil and Water Assessment Tool) to model the hydrology of the 2150 square miles Iroquios River watershed (IRW) located in the east central Illionis. Based on the completeness of the meteorological data, a nine year period of 1987-1995 is used for model calibration, and a 15 year period of 1972-1986 for model validation. Time series plots as well as statistical measures such as Nash-Sutcliffe efficiency (NSE), coefficient of correlation (r), and the per cent volume error between observed and simulated stream flow values on both monthly and annual bases were used to verify the simulation abilities of the models. Calibration and validation results from both HSPF and SWAT show that the models generally predict daily, and average monthly and annual stream flows close to the respective observed stream flows.

Enrique and Kevin (2005) described an application and field study in the Williams River, New South Wales, Australia designed to assess the impacts of point and non-point source pollution on water quality. Historical data were utilized for calibrating and validating the Hydrologic Simulation Program - Fortran (HSPF) with the BASINS GIS interface over the 1988-2000 period.

Results from the study indicate that short-duration, spatially extensive field campaigns provide useful data for enhancing modeling studies based on historical measurements at sparse sites. In addition, the study suggests that the conjunctive use of data collection and modeling is a step towards real-time integration of field data in hydrologic and water quality modeling efforts.

Irina *et al.* (2007) modeled the nitrogen and phosphorous concentrations in the Iskar River, Bulgaria, during the first flood event. They calibrated the HSPF model with the data for two years (2000-2001) and verified it using data for a further year for a sub-catchment of the river and it was then run for two time steps (i.e daily and hourly) for a flood event. Percentage differences between observed and simulated values for the nitrogen load were calculated as 13.1 and 18% for hourly and daily simulations, respectively. Percentage differences between phosphorus measured and simulated loads were larger at 16.6 and 34.4%. The simulations thus performed suggested that the further application of HSPF may be valuable for understanding and forecasting nutrient concentrations during first flood event.

Jeon *et al.* (2007) modified HSPF to simulate watershed pollutant loads in paddy farming regions. Dike height and the Dirac delta function were added to a modified HSPF code (HSPF-Paddy) to incorporate the behavior of ponded water and nutrients in rice paddy fields. HSPF-Paddy was validated by examining its application to a rice paddy plot (3000 m²) and a watershed (1803 km²) that contained a significant proportion of rice paddy fields (30%). The model efficiency at the plot scale was very high showing 0.52, 0.93, and 0.93 for ponded water depth, and accumulation of total nitrogen, and total phosphorus, respectively, and simulated values and observed data were in close agreement. Model efficiency was somewhat lower at the watershed scale showing 0.82, 0.78, 0.44, 0.61, and 0.63 for stream flow, temperature, 5-day biochemical oxygen demand, total nitrogen, and total phosphorus, respectively. However, model performance was generally within expectations, and generally model efficiency greater than 0.5 is deemed acceptable considering the complexity of the watershed in terms of size and land use.

Nasra *et al.* (2007) tested 3 mathematical models (soil water and analysis tools (SWAT), hydrological simulation program-FORTRAN (HSPF) and système hydrologique Européen Transport (SHETRAN)/grid oriented phosphorus component (GOPC)) of diffuse P pollution in three Irish catchments to explore their suitability in Irish conditions for future use in implementing the European Water Framework Directive. After calibrating the models, their daily flows and total phosphorus (TP) exports were compared and assessed. The HSPF model was the best at simulating the mean daily discharge while SWAT gave the best calibration results for daily TP loads. Annual TP exports for the three models and for two empirical models were compared with measured data.

Al-Abed and Al-Sharif (2008) calibrated the hydrologic component of the Hydrological Simulation Program - FORTRAN (HSPF) model for the Zarqa River Basin. The calibrated model could be used in a later stage to examine the impact of different management practices and climate change scenarios on the water resources in the basin. The calibration of the HSPF water quantity parameters was aided by GIS and by the automatic calibration model (PEST). The automatic calibration was done for the years 1988-1991 and the validation was done for the years 1996-1998. The coefficient of determination, R^2 for the calibration and verification years of the monthly flows was 0.81 and 0.76, respectively.

Salah and Nelson (2010) illustrated various hurdles & difficulties that the water resources engineers typically face in developing long term hydrological models using HSPF & WMS (Watershed Modeling System). The HSPF graphical user interface (GUI) in WMS is used to generate a User Control Input (UCI) file. The paper expands on this process by discussing various guidelines of running HSPF, viewing the generated hydrograph and finally calibrating the results. As a result, an efficient watershed-independent modeling process is presented, including concern-specific strategies to facilitate and speed up short and long term model development. It is recommended that these certain procedures be conducted to develop HSPF models in WMS. It is also recommended that this process can be used and extended to apply in short and long term simulations that incorporate water quality.

Liu and Tong (2011) adopted the HSPF model to develop a hydrologic and water quality model for the Upper Little Miami River basin, a headwater sub-watershed in Ohio, USA. After calibration and validation, the model was used to predict the hydrologic and water quality impacts under various scenarios of buffer zones. Results indicated that the 60, 90 and 120 m riparian forest and wetland buffers were able to reduce the mean annual flow by 0.26 to 0.28%, nitrite plus nitrate by 2.9 to 6.1%, and total phosphorus by 3.2 to 7.8%. By integrating environmental information and systems analysis, this study has demonstrated that HSPF is an effective tool to model nonpoint source pollution from riparian land-use changes, even in a small subwatershed with relatively minimal anthropogenic influences. The findings from this research may be useful in facilitating the development of management solutions.

Amirhossein *et al.* (2015) evaluated the capability of two different types of models including HSPF as a process based model and ANN as a data driven model in simulation of runoff for Balkhichai River Watershed in northwest of Iran. Statistical approach depending on cross-auto and partial-autocorrelation of the observed data is used as a good alternative to the trial and error method in identifying model inputs. The performances of ANN and HSPF models in calibration and validation stages are compared with the observed runoff values in order to identify the best fit forecasting model based upon a number of selected performance criteria. Results of runoff simulation indicated that the simulated runoff by ANN was generally closer to the observed values than those predicted by HSPF.

2.4 Land use land cover changes

Morse *et al.* (1994) developed a link between Geographical Information System (GIS) and a non-point source pollution model. The GIS ARC/INFO was linked to the agricultural non-point source pollution model and ORACLE data sources. Application of the system was demonstrated using the Bedford-Ouse catchment as a suitable case study. Water quality impacts were predicted from source data describing topography, soils, land use and river network. The model results were in agreement with observed nitrate concentrations at the catchment

outlet, and more appropriate data sources were considered to be the main priority for improving model predictive ability. Management scenarios were established to assess the impact of changing agricultural management practices on predicted water quality. The approach has significant potential for the management of agricultural pollution in the UK.

Carlson and Arthur (2000) used AVHRR & Landsat TM data to illustrate how the variables derivable from multi spectral satellite images would respond to urbanization with a case study of Chester County, PA — a region that has undergone rapid urban development over the past decade. Specific factors affecting the change in the surface microclimatic variables were discussed. Based on a statistical analysis of the Chester County data, future values of these microclimatic parameters can be predicted, given the characteristics of the initial land surface and an estimate of the change in vegetation and urban coverage.

Chou *et al.* (2003) studied the change in the land use pattern and the hydrologic cycle in many reservoir watershed areas due to the increased pressure on slope land development in Taiwan. This study was to integrate and analyze the impact to water conservation from deforestation or other land use pattern changes.

Yuan *et al.* (2005) developed a methodology to map and monitor land cover change using multi-temporal Landsat Thematic Mapper (TM) data in the seven-county Twin Cities Metropolitan Area of Minnesota for 1986, 1991, 1998, and 2002. The overall seven-class classification accuracies averaged 94% for the four years. The overall accuracy of land cover change maps, generated from post-classification change detection methods and evaluated using several approaches, ranged from 80 to 90%. The maps showed that between 1986 and 2002 the amount of urban or developed land increased from 23.7 to 32.8% of the total area, while rural cover types of agriculture, forest and wetland decreased from 69.6 to 60.5%. The results quantify the land cover change patterns in the metropolitan area and demonstrate the potential of multi-temporal Landsat data to provide an accurate, economical means to map and analyze changes in land cover over time.

Xiao *et al.* (2006) presented an integrated study of urbanization trends in Shijiazhuang City, Hebei Province of China, by using Geographical Information

Systems (GIS) and remote sensing. The study explored the temporal and spatial characteristics of urban expansion from 1934 to 2001, and land use/cover change from 1987 to 2001. Temporally, urban expansion showed fast and slow growth stages, with the high-speed growth districts shifting to the east or west side of the city. The remotely detected land use/cover change from 1987 to 2001 showed that the land use/cover was largely changed. The land use/cover conversion relationship implied that these changes are governed by urban expansion. Lastly, the major factors influencing urban expansion and land use/cover change were also discussed.

Reis (2008) investigated LULC changes by using Remote Sensing and Geographic Information Systems (GIS) in Rize, North-East Turkey. For this supervised classification technique was applied to Landsat images acquired in 1976 and 2000. The second part focused on land use land cover changes by using change detection comparison (pixel by pixel). In third part of the study, the land cover changes were analyzed according to the topographic structure (slope and altitude) by using GIS functions. The results showed that severe land cover changes have occurred in agricultural (36.2%), urban (117%), pasture (-72.8%) and forestry (-12.8%) in the region between 1976 and 2000. It was seen that the LULC changes mostly occurred in coastal areas and in areas having low slope values.

Badar *et al.* (2013) evaluated the impact of changing land use/land cover on the hydrological processes in Dal Lake catchment of Kashmir Himalayas by integrating remote sensing, simulation modeling and extensive field observations. The primary objective of this research was to help a better understanding of the LULC change, its driving forces and the overall impact on the hydrological response patterns. Multi-sensor and multi-temporal satellite data for 1992 and 2005 was used for determining the spatio-temporal dynamics of the lake catchment. Geographic Information System (GIS) based simulation model namely Generalized Watershed Loading Function (GWLF) was used to model the hydrological processes under the LULC conditions. The simulated results on the hydrological responses reveal that depletion of the vegetation cover in the study area and increase in impervious and bare surface cover due to anthropogenic

interventions are the primary reasons for the increased runoff, erosion and sediment discharges in the Dal lake catchment. This study concludes that LULC change in the catchment is a major concern that has disrupted the ecological stability and functioning of the Dal lake ecosystem.

Romshoo and Rashid (2014) assessed and correlated the spatio-temporal changes in the land cover system within a Himalayan wetland and its catchment using a time series satellite, historical, and field data. Significant changes in the spatial extent, water depth, and the land system of the Hokersar wetland were observed from the spatiotemporal analysis of the data from 1969 to 2008. The wetland area has shrunk from 18.75 km² in 1969 to 13 km² in 2008 with drastic reduction in the water depth of the wetland. The marshy lands, habitat of the migratory birds, have shrunk from 16.3 km² in 1969 to 5.62 km² in 2008 and have been colonized by various other land cover types. Significant changes in the forest cover (88.33-55.78 km²), settlement (4.63-15.35 km²), and water bodies (1.75-0.51 km²) were observed in the catchment. It is concluded that the urbanization, deforestation, changes in the hydrologic and climatic conditions, and other land system changes observed in the catchment are the main causes responsible for the depleting wetland extent, water depth, and biodiversity by adversely influencing the hydrologic erosion and other land surface processes in the catchment.

Yang *et al.* (2016) used two land scenarios (1995 and 2010) to evaluate the impact of land use changes on NPS pollutants loading in basins upstream of Three Gorges Reservoir (TGR), using a calibrated and validated version of the soil and water assessment tool (SWAT) model. The study area included the basins of the Dong and Puli Rivers, two major tributaries of the Pengxi River which is one of the largest tributaries of the Yangtze River upstream of the TGR. The results indicated that the calibrated SWAT model could successfully reproduce the loading of NPS pollutants in the basins of the Dong and Puli Rivers. The precipitation showed a non-significant influence on NPS pollutants loading. The different types of land use change were sensitive to NPS pollutants as well as land use pattern. The influence of background value of soil nutrient on NPS pollutants loading was evaluated in upland and paddy field. It was found that total nitrogen (TN) and total phosphorous (TP) in upland were more sensitive to NPS pollutants loading than in paddy fields.

Chapter-3

MATERIALS AND METHODS

3.1 Study area

The study area is the Dal Lake catchment (Fig. 3.1), which is situated between the geographical coordinates of 34°02'- 34°13' N latitude and 74°50 ' - 75°09' E longitude. The catchment has an area of 337 km². The Dal Lake is situated in the heart of Srinagar (elevation- 1587 m above mean sea level) and has a surface area of 15.21 sq.km (calculated using ArcGIS).

The Dal Lake is a multi-basin lake (Fig. 3.2) and is believed to be fed by a number of underground springs, having both inflow and outflow channels. The main source is the Telbal Nallah that originates from Marsar Lake high up in the mountains and enters the lake from the northern side and drains the Dachigam reserve enroute. On the southwest side the surplus water flows via Dalgate into Cshunthkul, which is a tributary to the river Jehlum. There is another outlet channel, the Nallah Amir Khan connecting the nigeen basin to Anchar Lake. Settlements include Hazratbal, Nishat, Shalimar, Gagribal, Dalgate, Khayam, Khanyar, Saida Kadal and Rainawari.

The western portion of the watershed is a flatter area as compared to the northern and the eastern sides that rise high. The catchment has a varied topography with a range of the altitudes varying between 1580 and 4360 metres. The climate of the area is sub-humid temperate with the average monthly temperature of 13.5°C and average rainfall of 677 mm at Srinagar and 870 mm at Dachigam. (IITM, Pune).

Three different sites were selected in the catchment area for determination of different water quality parameters by using the model HSPF. The selected sites were Hazratbal, Telbal and Gagribal and were numbered as Site 1, 2 and 3 respectively (Fig. 3.3).

3.2 Model selection

Water quality modeling involves the prediction of water pollution using mathematical simulation techniques. A typical water quality model consists of a

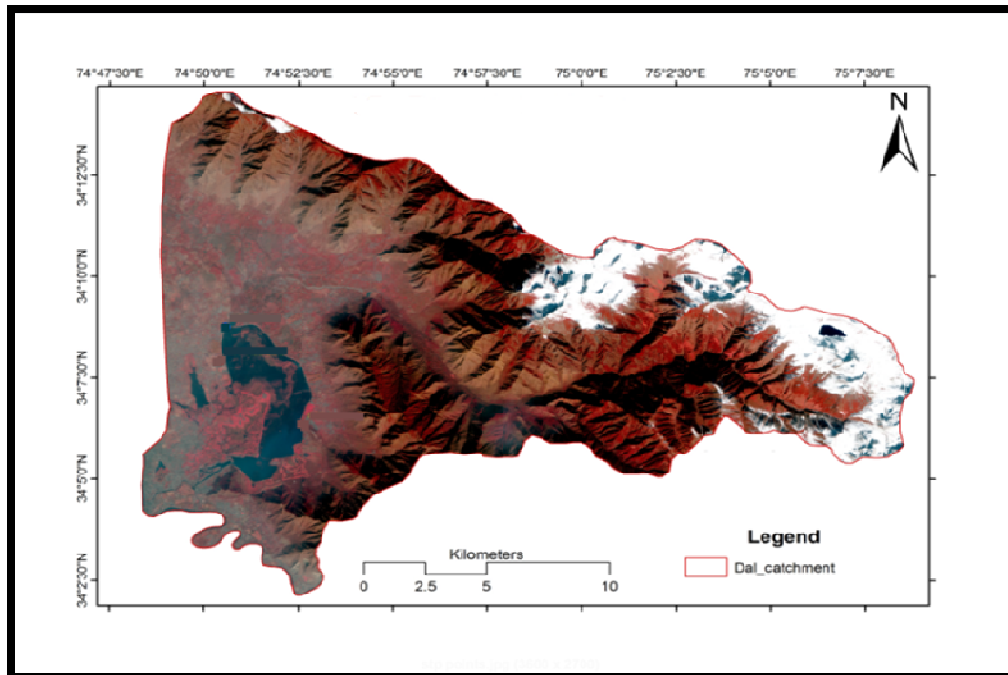


Fig. 3.1: LISS IV Image of Catchment Area of Dal Lake

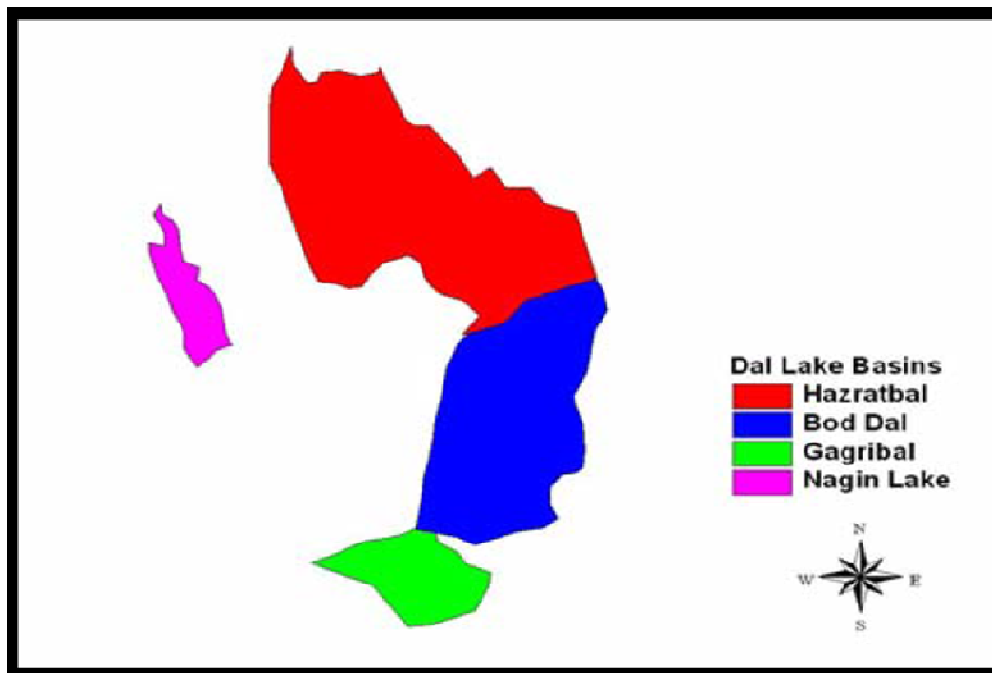


Fig. 3.2: Dal Lake Basins

collection of formulations representing physical mechanisms that determine position and momentum of pollutants in a water body.

Hydrologic modeling has served as a valuable tool in water resources management for many years. Simulating the hydrologic and water quality behavior of a watershed of interest is usually used to predict the impacts of proposed land use scenarios and to evaluate management strategies on both short and long term basis.

Water quality models have improved considerably over the last two decades, which has improved the reliability of model output and gives water resource/quality engineers' better understanding of the real world problems. Watershed management was initially used to control or reduce flooding, but now it is commonly employed to control development induced impacts caused by increases in pollutant loading, peak runoff rates and volumes. In the context of watershed management, a typical computer model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate naturally occurring land-based processes over an extended period of time, including hydrology (flow) and pollutant transport (water quality).

Models can also be used to assess the potential benefits of various restoration scenarios (e.g., implementation of best management practices).

The model that will be used here is HSPF (Hydrologic Simulation Program Fortran) and Fig. 3.4 shows a flowchart of the model.

3.3 Data required for modeling

Meteorological data including hourly precipitation (inches), air temperature (Fahrenheit), dew point (Fahrenheit), solar radiation (Langley's), cloud cover (Tenths) and wind speed (m/s) for the catchment area were collected from Automatic weather station (AWS) of the University of Kashmir, Hazratbal. Data of the pesticides was collected from the Qualitative Research Analysis Laboratory, SKUAST-K, Shalimar. The satellite imagery of the catchment area were provided by the Centre for Climate Change and Mountain Agriculture (CCCMA), SKUAST-K, Shalimar which were then further used for the preparation of the land use land cover map, streams cover, identification of point sources of pollution and preparation of sub basins layer of the

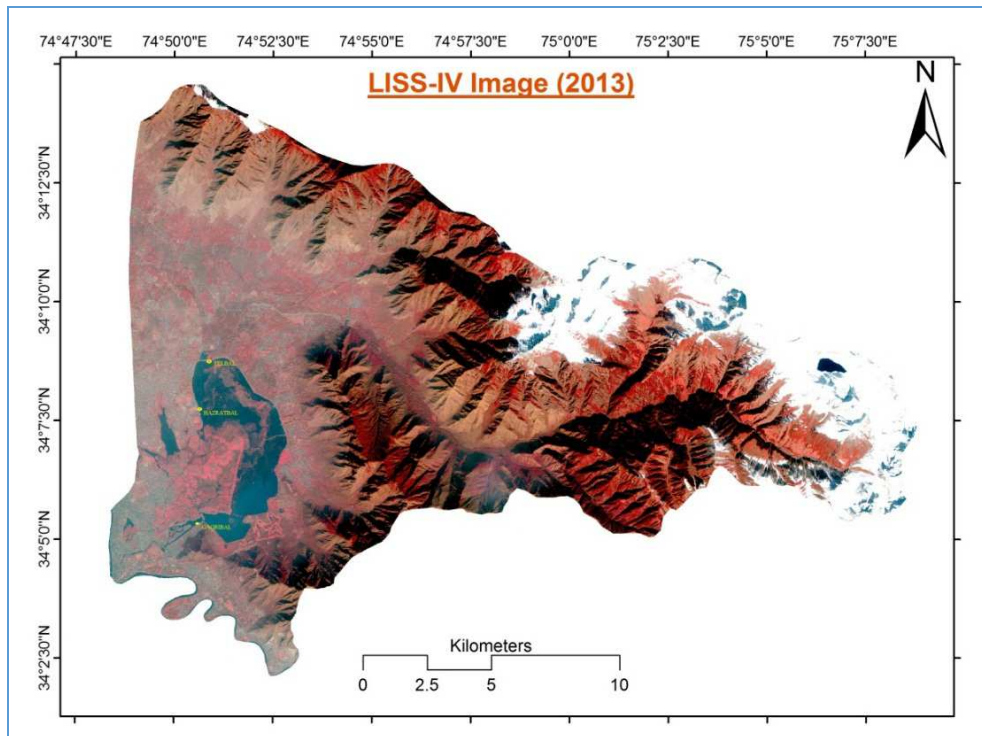


Fig. 3.3: Selected sites for estimation of water quality parameters

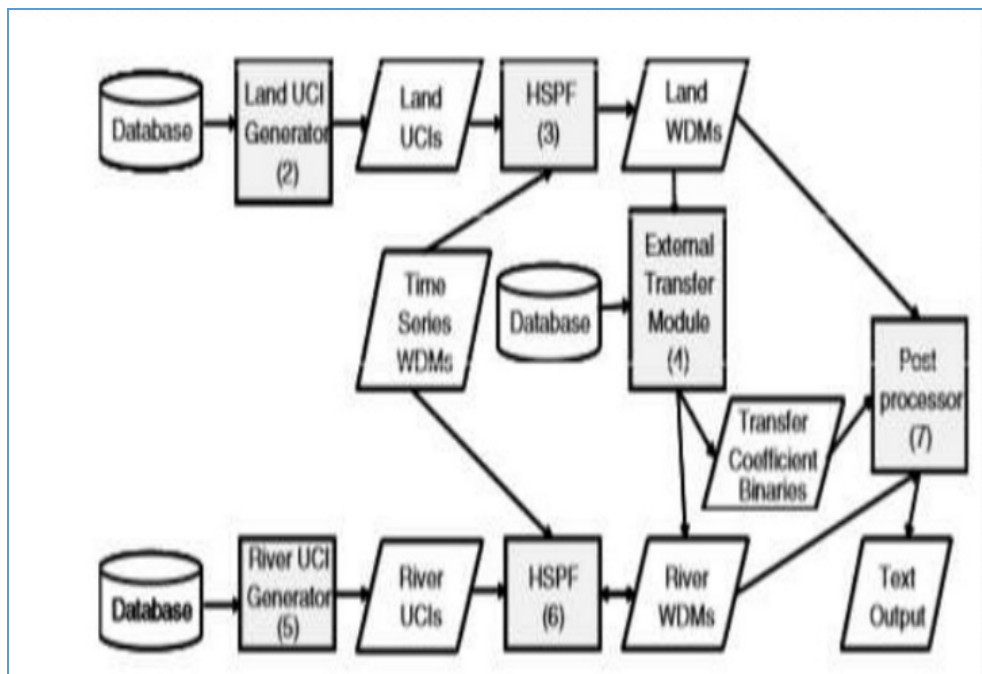


Fig. 3.4: Flowchart of the model HSPF

catchment area of Dal Lake. The nutrient data collected at different sites by Lakes and Waterways Development Authority (LAWDA), Kashmir (Hazratbal, Gagribal, and Telbal). The data was provided for nitrogen, nitrates-nitrites, ammonia, phosphorous, phosphates, carbon, oxygen, TSS and turbidity for the period from April 2012 to December 2014.

3.4 Preparation of land use/land cover maps using Arc GIS

Satellite images (LISS IV image for 2013 and LandSat image for 1991, provided by CCCMA, SKUAST-K) were interpreted using unsupervised and supervised classification and various land uses were identified. Arc GIS 10.2 was used to digitize the catchment area images for preparing LULC maps, Stream cover, sub basin layer and point sources map of the area. The LULC of the years 1991 and 2013 were then compared to detect the land use changes in the area for the determination of management practices change in the area.

In both the satellite images of the catchment area for the years 1991 (Fig. 3.5) and 2013 (Fig. 3.6) a total of 13 land use classes were identified viz. water body, agriculture field, orchards and horticulture, vegetable field, mixed vegetation, evergreen forests, open forests, grasslands and meadows, scrub land, barren land, wetland, built up and recreational park.

3.5 Overview of HSPF

The Hydrological Simulation Program-Fortran (HSPF) is a semi-distributed watershed model, which simulates hydrology & water quality processes at user-specified spatial & temporal scales. It is an EPA (Environment Protection Agency, USA) watershed hydrology & pollutant transport model & the core watershed model in BASINS (Better Assessment Science for Point & Non point Sources) modeling system. It is used in the prediction of flow rate, sediment load & nutrient and pesticide concentrations. It can simulate associated water quality for both conventional & toxic organic pollutants on pervious & impervious land surfaces & in streams and well mixed impoundments. It consists of a set of modules arranged in a hierarchical structure, which permit the continuous simulation of a comprehensive range of hydrological & water quality processes. The software is planned around a time series management system operating on direct access principles.

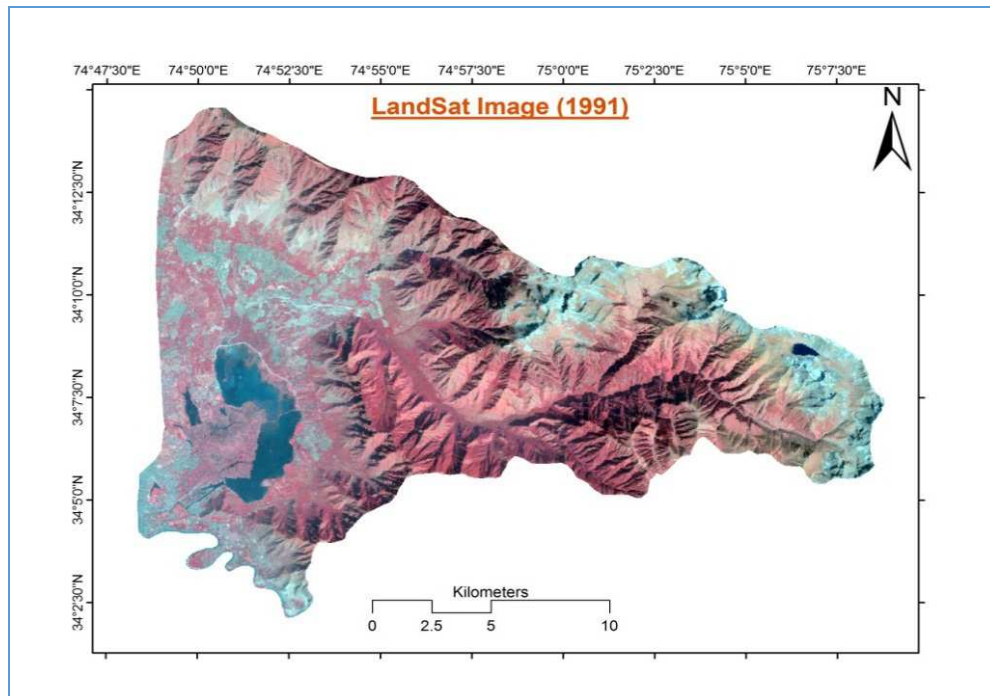


Fig. 3.5: LandSat Image of the Catchment Area for the year 1991

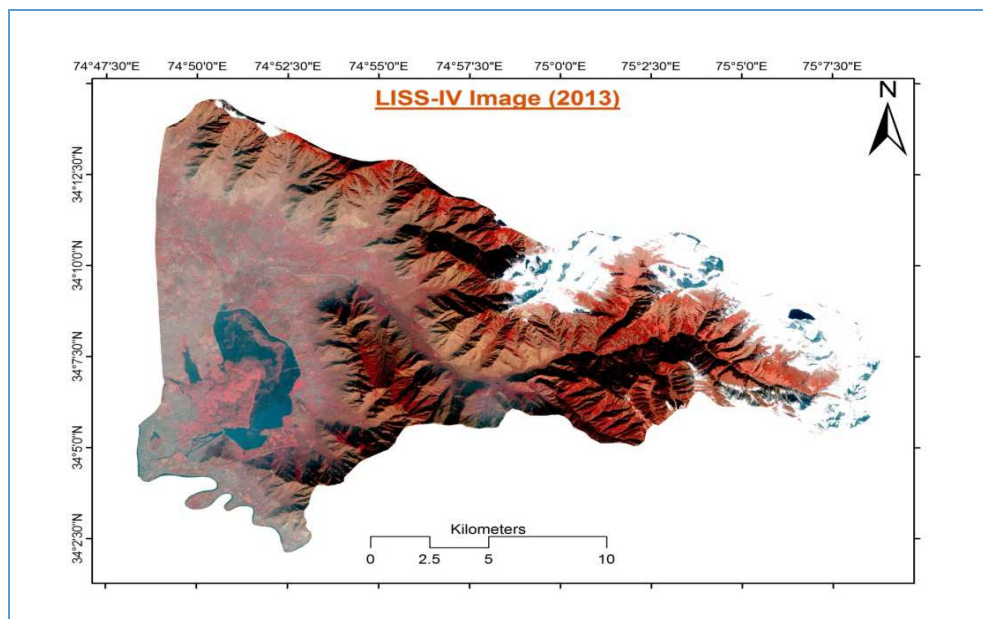


Fig. 3.6: LISS IV Image of the Catchment Area for the year 2013

The model can forecast the runoff, sediment loads and pollutant amount. It is a continuous simulation model that gathers hydrology, hydraulics, soil erosion, sediment loads and water quality. HSPF sub-divides land surface areas into pervious and impervious, it is applicable to watersheds with mixed land uses.

3.5.1 HSPF development and interface

With its predecessors dating back to the 1960s, HSPF is a culminating evolution of the Stanford Watershed Model (SWM) (Crawford and Linsley, 1966), watershed-scale Agricultural Runoff Model (ARM) (Donigian *et al.*, 1977), Nonpoint Source Loading Model (NPS) (Donigian and Crawford, 1976) and Sediment and Radionuclides Transport (SERATRA) (Onishi and Wise, 1979). HSPF is currently in version 12.2 (Bicknell *et al.*, 2005). In order to improve the efficiency of using HSPF, WinHSPF was designed as an interactive Windows interface to HSPF, and fully-integrated into a multipurpose environmental analysis system - Better Assessment Science Integrating point and Nonpoint Sources (BASINS) system, developed by United States Environmental Protection Agency (USEPA) based on Geographic Information System (GIS) foundation for performing watershed and water quality-based studies (Lahlou *et al.*, 1998). User control input (UCI) files are used for data exchange among WinHSPF, BASINS and GIS. Within the BASINS system, WinHSPF is intended to be used in conjunction with the interactive program known as GENeration and analysis of model simulation SCeNarios-(GenScn) to analyze results of model simulation scenarios and their comparison. HSPF was applied through BASINS and WinHSPF software packages. Fig. 3.7 – 3.15 illustrate the working of HSPF.

3.5.2 Theoretical description of HSPF

HSPF has four application modules, i.e., PERLND for pervious land segments, IMPLND for impervious land segments, RCHRES for river reaches and well-mixed reservoirs, and BMP for simulating constituent removal efficiencies associated with implementing management practices (Donigian and Imhoff, 2002; Bicknell *et al.*, 2005). PWATER, key component of module PERLND, was designed to calculate the components of the water budget, and to predict the total runoff from a previous area. The algorithms used to simulate these land related

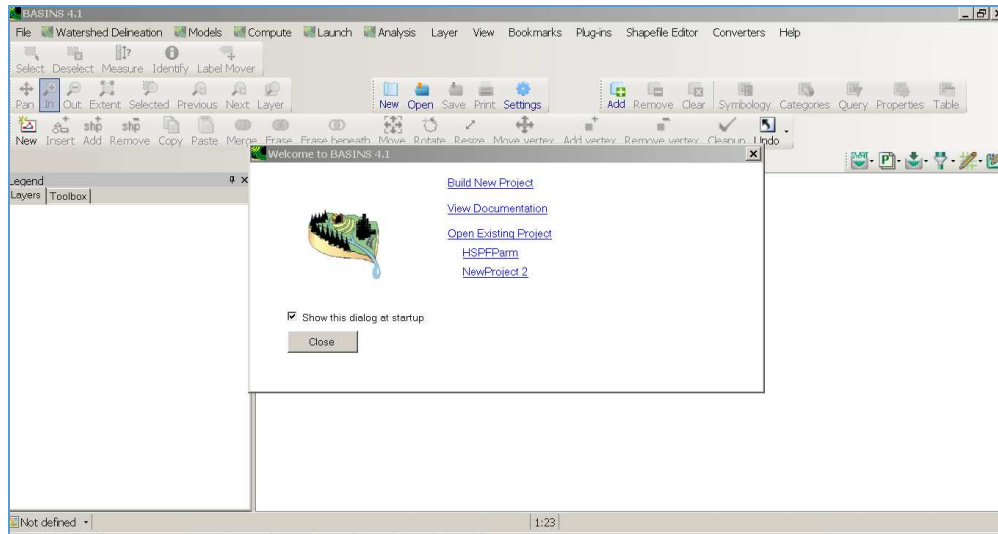


Fig. 3.7: Main menu of BASINS

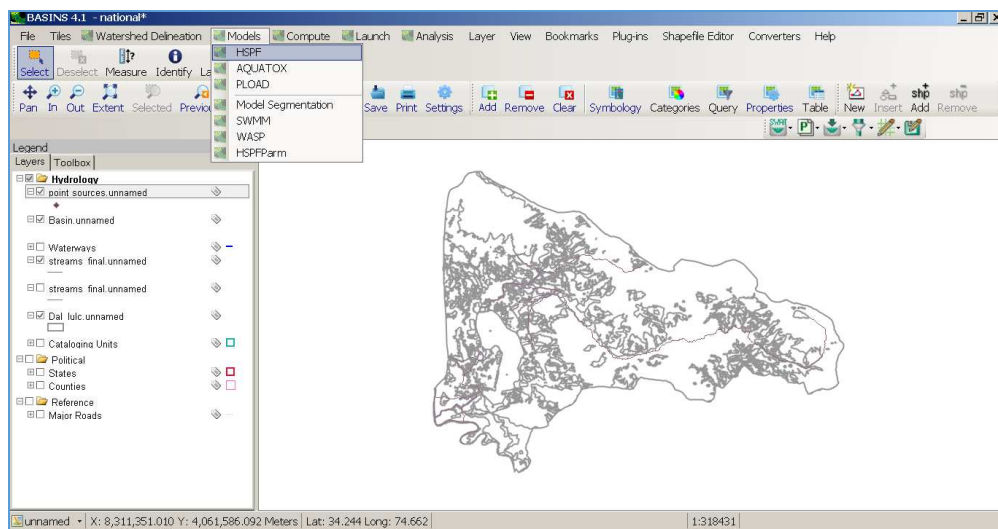


Fig. 3.8: Input for HSPF

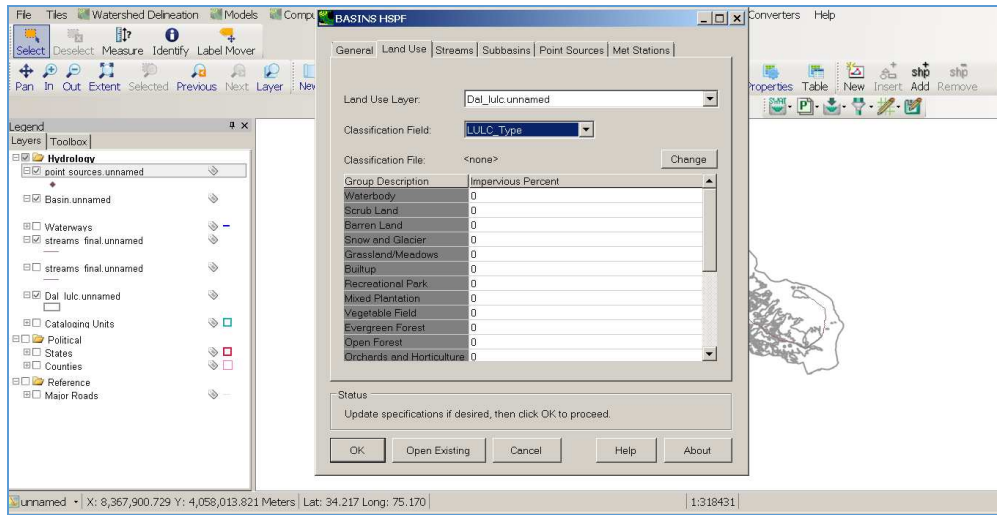


Fig. 3.9: Attribute Table of LULC

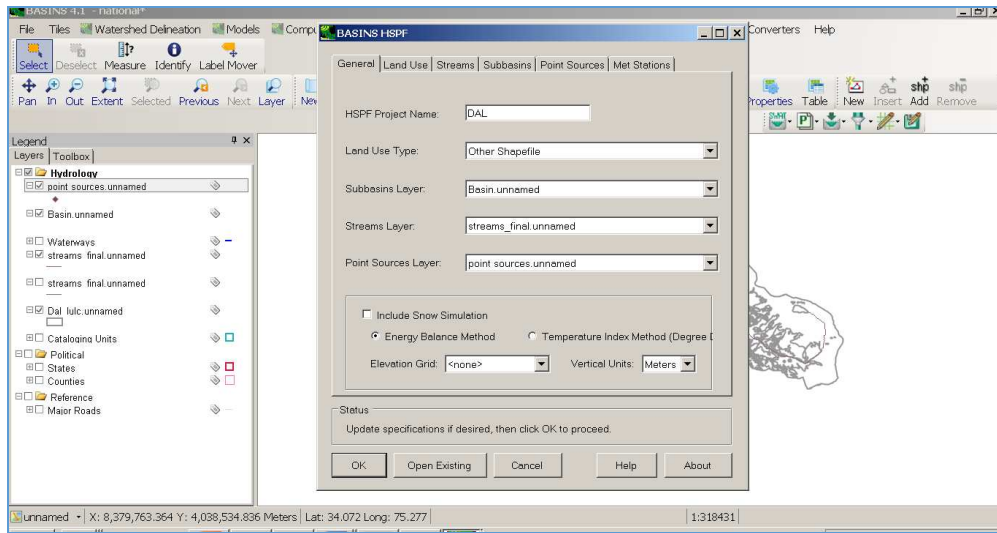


Fig. 3.10: Creating UCI file for HSPF

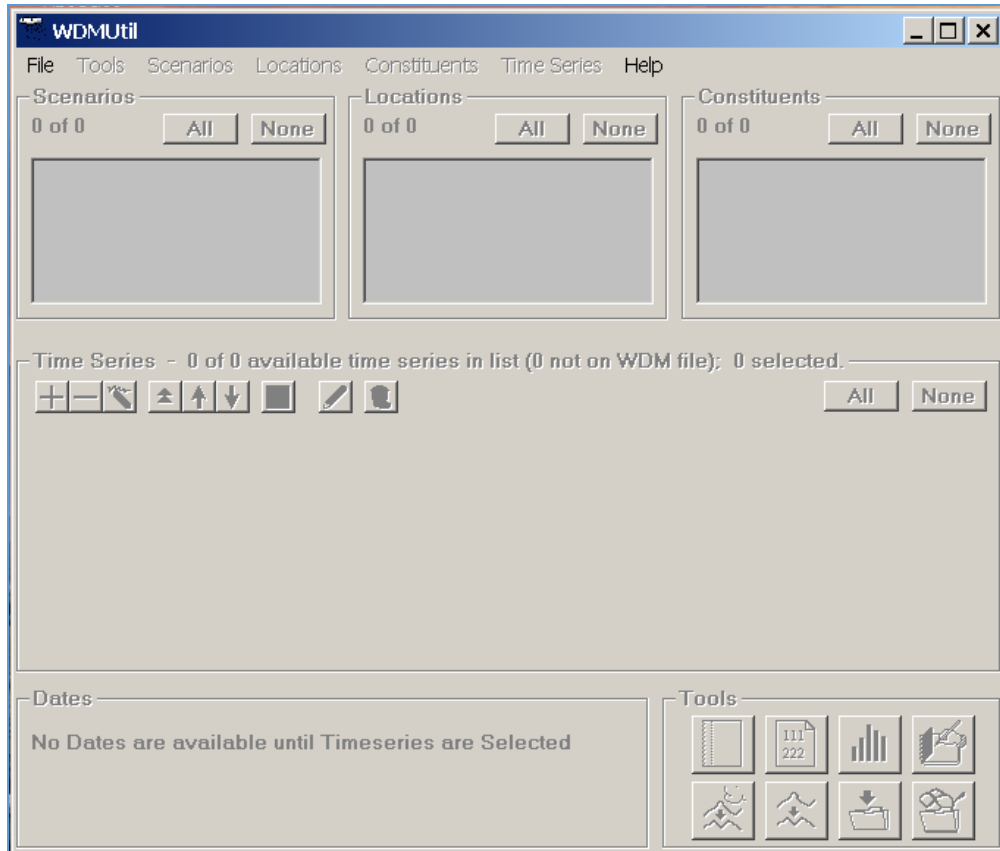


Fig. 3.11: WDMutil pugin

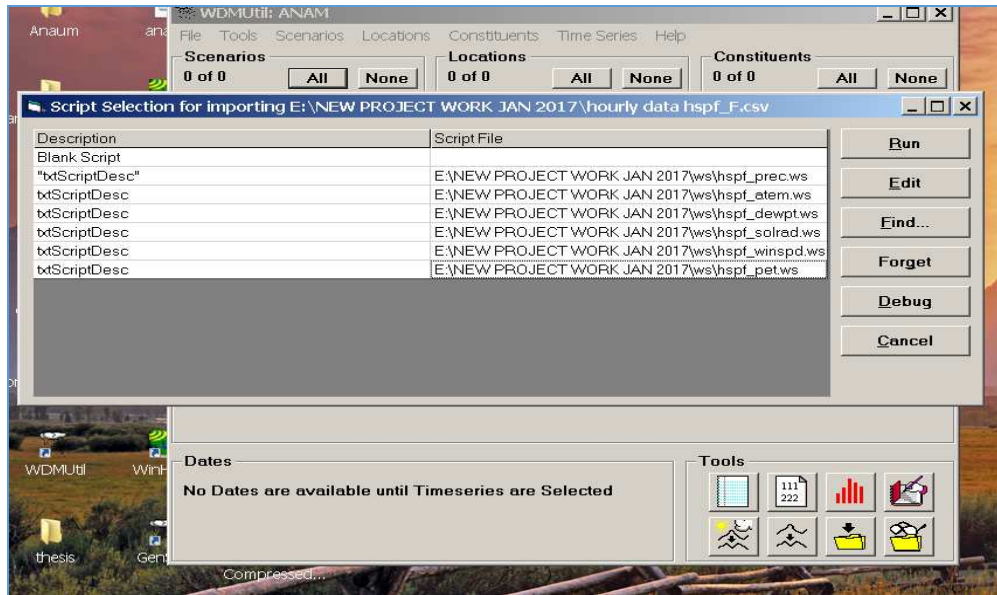


Fig. 3.12: Script creating wizard

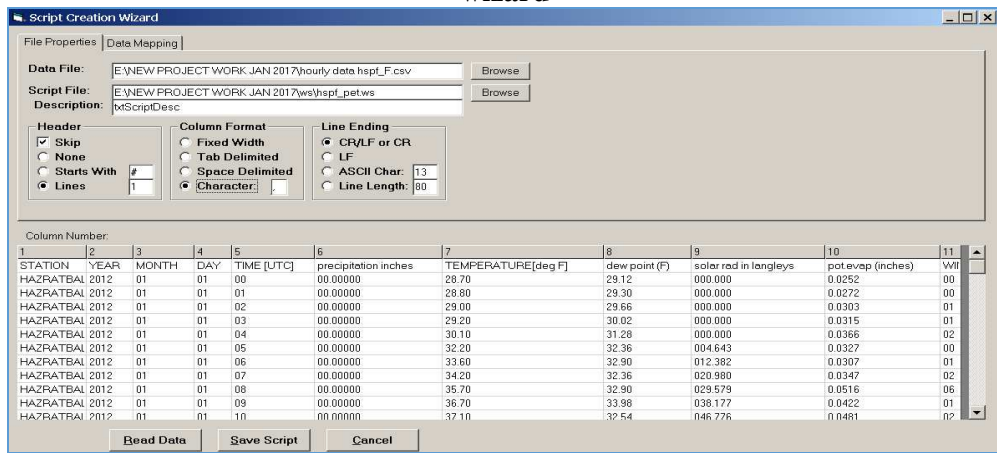


Fig. 3.13: Script file

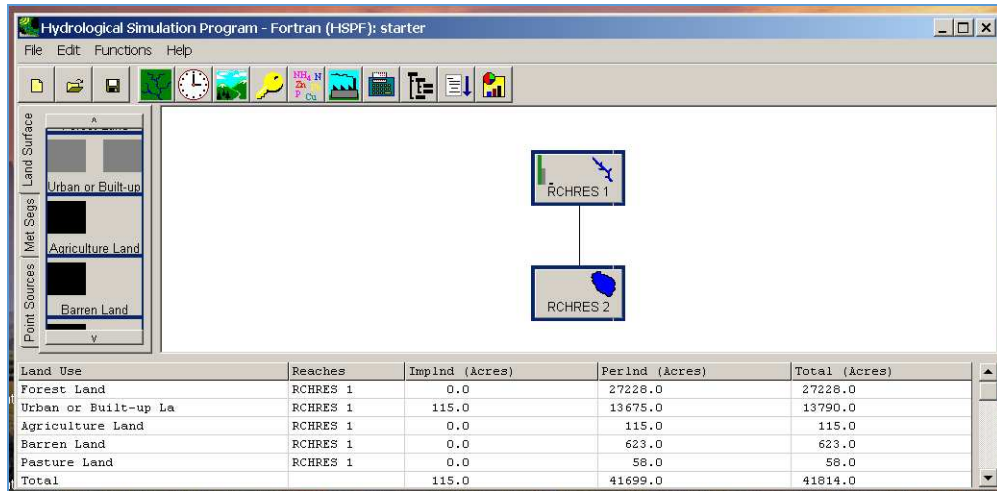


Fig. 3.14: WinHSPF start up

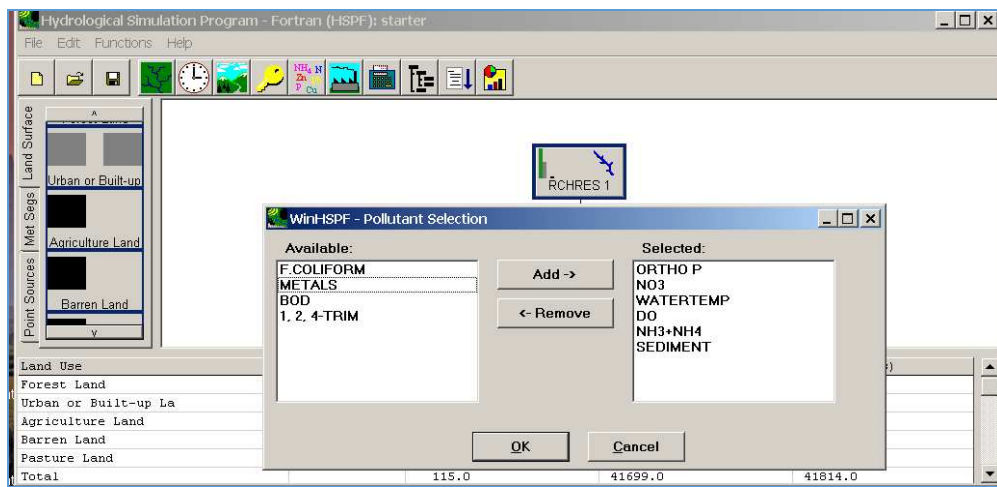


Fig. 3.15: WinHSPF pollutant simulation

processes, the product of over 15 years of research and testing, are based on the original research for the LANDS subprogram of the SWM IV (Crawford and Linsley, 1966). PERLND and IMPLND processes are simulated through water budget, and the generation and transport of water quality constituents and sediment. Empirical equations are adopted in HSPF for the 16 calculations of interception, evapotranspiration, overland flow, interflow, infiltration and groundwater loss processes. Sediment production in HSPF is based on detachment and scour from a soil matrix and transport by overland flow in pervious areas, whereas solids buildup and wash-off are simulated for impervious areas. HSPF includes modules to simulate nutrients cycling processes. The nitrogen biochemical process in HSPF includes plant uptake of nitrate and ammonium, return of plant nitrogen to organic nitrogen, de-nitrification or reduction of nitrate-nitrite, immobilization of nitrate-nitrite and ammonium, mineralization of organic nitrogen, fixation of atmospheric nitrogen, volatilization of ammonium, adsorption or desorption of ammonium, and partitioning of two types of organic nitrogen between solution and particulate forms. A PHOS module in HSPF is designed to simulate the behavior of phosphorus in a previous land segment by modeling the transport, plant uptake, adsorption, desorption, immobilization, and mineralization of the various forms of phosphorus. Because phosphorus is readily tied to soil and sediment, it is usually scarce in streams and lakes.

The utility modules of HSPF include COPY (copies time series data), MUTSIN (makes the time series data based on the external file available for use by other modules), PLTGEN (writes a sequential external file containing up to 10 time series and related commands for a stand-alone plotting program), DURANL (examines the behavior of a time series and computes a variety of statistics related to its excursions above and below certain specified levels), GENER (performs any one of several transformations on one or more input time series), DISPLY (prints time series data in a tabular format and summaries of the data) and REPORT (produces time series output in a very flexible fashion).

3.5.3 HSPF modeling

The HSPF modeling work consisted of building a BASINS project, watershed delineation, setting up WinHSPF environment, time series data preparations, surface water quantity and quality simulation, calibration, and validation. The BASINS project of the study area was built on the ArcView 3.1 platform by choosing data projection, importing land use, DEM, hydrography, and soil data. Watershed delineation was carried out using GIS extensions provided by BASINS to automatically divide study area into hydrologically connected segments or sub-watersheds for detailed watershed characterization and modeling.

Meteorological time series data were managed using Watershed Data Management Utility program (WDMUtil) of BASINS. Hourly precipitation, air temperature, wind speed, dew-point, solar radiation, and evapotranspiration were reformatted, generated, aggregated, disaggregated, and calculated in WDM. A HSPF project was built using the data of watershed boundary, streams, outlets and land use in the BASINS project, and the weather station time series in WDM files (the principal library for storage of time series). Land uses in the area include orchards and horticulture, agriculture field, vegetable cultivation, evergreen forests, snow and glacier, grasslands and meadows, wetland, open forests, scrub land, barren land, mixed vegetation, recreational parks and built up.

3.5.4 Parameter estimation

When a HSPF project was created from BASINS, an UCI file was created to hold and supply parameters to HSPF. The estimation of a large array of parameter values was required to quantitatively represent/depict the watershed hydrological cycle and water quality. Although BASINS can estimate many input parameters using available information in GIS database to improve the efficiency of HSPF applications, these values could be highly inaccurate and should be manually modified if more accurate information is available. Based on these initial parameter values, manual parameter estimation work were carried out using monitoring data and the results of previous researches and experiments in the study area (Bicknell *et al.*, 2005). The initial conditions, such as temperature, amount of soil moisture at the start of the simulation were determined by

observation data. In general, parameters in HSPF fall into two categories, fixed parameters and process-related parameters (Al-Abed and Whiteley, 2002). The values of fixed parameter remain constant throughout a simulation period. Since the process related parameters (such as soil water amount, nutrients transport in soil) have no directly measurable physical analogues, their proper values were determined in the calibration and validation processes.

3.5.5 Calibration and validation

The calibration of the present study was done from April 2012 to April 2013 and the calibrated results were then validated for the data from May 2013 till December 2014.

Calibration and validation have been defined by the American Society of Testing and Materials as follows (ASTM, 1984):

- Calibration is a test of the model with known input and output information that is used to adjust or estimate factors for which data are not available.
- Validation is a comparison of model results with numerical data independently derived from experiments or observations of the environment.
- Application of HSPF for predicting flow, sediment, and chemical loadings can be described as comprised of three phases,
 - Phase I includes:
 - Data collection,
 - Model input preparation, and
 - Parameter evaluation, i.e., all the steps needed to set up a model, characterize the watershed, and prepare for model executions.

- Phase II is the model testing phase, which involves:
 - Calibration,
 - Validation (or verification, as it is sometimes called). This is the phase in which the HSPF model is evaluated to assess whether it can reasonably represent the watershed behavior, for the purposes of the study.
- Phase III includes the ultimate use of the model, as a decision support tool for management and regulatory purposes. Although specific application procedures for all watershed models differ due to the variations of the specific physical, chemical, and biological systems that they each attempt to represent, they have many steps in common. The calibration and validation phase is especially critical since the outcome establishes how well the model represents the watershed for the purpose of the study. Thus, this is the “bottom line” of the model application effort, as it determines if the model results can be relied upon and used effectively for decision-making. Model validation is in reality an extension of the calibration process. Its purpose is to ensure that the calibrated model properly assesses all the variables and conditions that can affect model results. While there are several approaches to validating a model, perhaps the most effective procedure is to use only a portion of the available record of observed values for calibration; once the final parameter values are developed through calibration, simulation is performed for the remaining period of observed values, and goodness-of-fit between the recorded and simulated values is reassessed. This type of split-sample calibration/validation procedure is commonly used, and recommended, for many watershed modeling studies. Model credibility is based on the ability of a single set of parameters to represent the entire range of observed data. If a single parameter set can reasonably represent a wide range of events, then this is a form of validation. In practice, the model calibration/validation process can be viewed as a systematic analysis of errors or differences between model predictions and field observations. These types of analyses require

evaluation of the accuracy and validity of the model input data, parameter values, model algorithms, calibration accuracy, and observed field data used in the calibration/validation. Clearly, the model user must become a detective, searching for the causes of the errors or differences, and for potential remedies to improve the agreement and reduce the errors.

Watershed model performance, i.e., the ability to reproduce field observations, and calibration/validation are most often evaluated through both qualitative and quantitative measures, involving both graphical comparisons and statistical tests. For flow simulations where continuous records are available, all these techniques are employed, and the same comparisons will be performed, during both the calibration and validation phases. Comparisons of simulated and observed state variables will be performed for daily, monthly, and annual values, in addition to flow-frequency duration assessments. Statistical procedures include error statistics, correlation and model-fit efficiency coefficients, and goodness-of-fit tests. For sediment, water quality, and biotic constituents, model performance will be based primarily on visual and graphical presentations, as the frequency of observed data is often inadequate for accurate statistical measures. However, alternative model performance assessment techniques for water quality, e.g., error statistics and correlation measures, consistent with the population of observed data available are often used for model calibration and testing.

3.6 Water quality parameters

3.6.1 Temperature

Water temperature is affected by air temperature, storm-water runoff, groundwater inflows, turbidity, and exposure to sunlight. In considering the health of organisms, it is necessary to consider their maximum temperature and optimum temperature. The maximum temperature is the highest water temperature at which the organism will live for a few hours. The optimum temperature is the temperature at which it will thrive.

The atmospheric temperature at the sampling site was recorded with the help of Celsius thermometer, avoiding its exposure of mercury bulb to direct sunlight (Source: LAWDA).

3.6.2 pH

pH is a measure of a solution's acidity. In water, small numbers of water molecules (H_2O) will break apart or disassociate into hydrogen ions (H^+) and hydroxide ions (OH^-). Other compounds entering the water may react with these, leaving an imbalance in the numbers of hydrogen and hydroxide ions. When more hydrogen ions react, more hydroxide ions are left in solution and the water is basic; when more hydroxide ions react, more hydrogen ions are left and the water is acidic. pH is a measure of the number of hydrogen ions and thus a measure of acidity.

The pH of the water samples was measured by using an Elico-digital pH meter. Before use the pH meter was calibrated each time against buffer solutions of known Hydrogen ion concentration usually on pH 4, pH 7 or pH 9.

pH is measured on a logarithmic scale between 1 and 14 with 1 being extremely acid, 7 neutral, and 14 extremely basic. Because it is a logarithmic scale there is a tenfold increase in acidity for a change of one unit of pH, e.g. 5 is 100 times more acid than 7 on the pH scale. The largest variety of freshwater aquatic organisms prefers a pH range between 6.5 and 8.0 (Source: India Water Portal).

3.6.3 Turbidity

Turbidity is a measure of how particles suspended in water affect water clarity. It is an important indicator of suspended sediment and erosion levels. Typically it will increase sharply during and after a rainfall, which causes sediment to be carried into the creek. Elevated turbidity will also raise water temperature, lower dissolved oxygen, prevent light from reaching aquatic plants which reduces their ability to photosynthesize, and harm fish gills and eggs.

3.6.4 Dissolved oxygen

Dissolved oxygen is oxygen gas molecules (O_2) present in the water. Plants and animals cannot directly use the oxygen that is part of the water molecule (H_2O), instead depending on dissolved oxygen for respiration. Oxygen enters streams from the surrounding air and as a product of photosynthesis from aquatic

plants. Consistently high levels of dissolved oxygen are best for a healthy ecosystem.

Levels of dissolved oxygen vary depending on factors including water temperature, time of day, season, depth, altitude, and rate of flow. Water at higher temperatures and altitudes will have less dissolved oxygen. Dissolved oxygen reaches its peak during the day. At night, it decreases as photosynthesis has stopped while oxygen consuming processes such as respiration, oxidation, and respiration continue, until shortly before dawn.

Human factors that affect dissolved oxygen in streams include addition of oxygen consuming organic wastes such as sewage, addition of nutrients, changing the flow of water, raising the water temperature, and the addition of chemicals.

Dissolved oxygen is measured in mg/L.

0-2 mg/L	not enough oxygen to support life
2-4 mg/L	only a few fish and aquatic insects can survive
4-7 mg/L	good for many aquatic animals, low for cold water fish
7-11 mg/L	very good for most stream fish

(Source: IS 10500:2012)

To a sample collected in a 250 ml glass bottle, 1 ml of each magnesium sulphate solutions and alkaline iodide azide solution was added one after the other with separate pipettes. The precipitate (mangnous hydroxide floc) formed was dissolved after about four minutes with the help of concentrated Sulphuric acid. The fixed samples were carried to the laboratory where these were titrated against 0.025 N Sodium thiosulphate solution, using starch solution as indicator. The end point was noted at the first disappearance of blue color. The amount of DO present was then calculated by using the formula. (APHA,1998)

$$\text{DO (mg/l)} = \text{Vol. of the titrant} \times 0.2 \times 1000 \text{ Vol. of sample}$$

Where, 0.2 represents 1 ml of sodium thiosulphate equivalent to 0.2 mg of oxygen.

3.6.5 Nitrate

Nitrogen is abundant on earth, making up about 80% of our air as N_2 gas. Most plants cannot use it in this form. However, blue-green algae and legumes have the ability to convert N_2 gas into nitrate (NO_3^-), which can be used by plants. Plants use nitrate to build protein, and animals that eat plants also use organic nitrogen to build protein. When plants and animals die or excrete waste, this nitrogen is released into the environment as NH_4^+ (ammonium). This ammonium is eventually oxidized by bacteria into nitrite (NO_2^-) and then into nitrate. In this form it is relatively common in freshwater aquatic ecosystems. Nitrate thus enters streams from natural sources like decomposing plants and animal waste as well as human sources like sewage or fertilizer.

Nitrate is measured in mg/L. Natural levels of nitrate are usually less than 1 mg/L. Concentrations over 10 mg/L will have an effect on the freshwater aquatic environment. 10 mg/L is also the maximum concentration allowed in human drinking water by the U.S. Public Health Service. For a sensitive fish such as salmon the recommended concentration is 0.06 mg/L.

For Nitrite determination in the samples, to 50 ml of colorless filtered sample 1 ml of each EDTA, Sulphanilic acid, naphthylamine hydrochloride and sodium acetate solutions in sequence were added. A wine red color appeared in the presence of nitrites (APHA).

For Nitrate determination in the samples, to 100 ml of the sample 1 ml of zinc sulphate ($ZnSO_4$) and 0.5 ml of 6N NaOH one after the other was added. It was then allowed to stand for 10 minutes till the whole precipitate settled at the bottom of flask. Then 50 ml of supernatant sample were taken carefully, so that no precipitate remained there in the solution and one drop of EDTA and 2 ml of Nesler reagent were added to this aliquot. It was allowed to stand for 10 minutes (APHA).

Water with low dissolved oxygen may slow the rate at which ammonium is converted to nitrite (NO_2^-) and finally nitrate (NO_3^-). Nitrite and ammonia are far more toxic than nitrate to aquatic life.

3.6.6 Phosphate

Phosphorus in small quantities is essential for plant growth and metabolic reactions in animals and plants. It is the nutrient in shortest supply in most fresh waters, with even small amounts causing significant plant growth and having a large effect on the aquatic ecosystem. Phosphate-induced algal blooms may initially increase dissolved oxygen via photosynthesis, but after these blooms die more oxygen is consumed by bacteria aiding their decomposition. This may cause a change in the types of plants which live in an ecosystem.

Sources of phosphate include animal wastes, sewage, detergent, fertilizer, disturbed land, and road salts used in the winter.

Phosphates do not pose a human or health risk except in very high concentrations. It is measured in mg/L. Larger streams may react to phosphate only at levels approaching 0.1 mg/L, while small streams may react to levels of PO_4^{3-} at levels of 0.01 mg/L or less. In general, concentrations over 0.05 will likely have an impact while concentrations greater than 0.1 mg/L will certainly have impact on a river.

For determining Orthophosphate in the samples, to 100 ml of water sample, one drop of phenolphthalein indicator was added. After the appearance of pink color, strong acid was added to decolorize it. Then 4 ml of ammonium molybdate and 0.5 ml of stannous chloride one after the other were added and the solution was allowed to stand for 10 minutes to develop color. And the reading was taken (APHA).

For determining total phosphate in the water samples, to 25 ml of water sample 1 ml of H_2SO_4 and 5 ml of HNO_3 one after the other were added. The solution was digested over the hot plate. After cooling off the flasks, 20 ml of distilled water and one drop of phenolphthalein indicator were added. It was then titrated against 1 N NaOH till pink color appeared. The sample volume was raised up to 100 ml by adding distilled water and 1-2 drops of strong acid solution to discharge the pink color. Then 4 ml of ammonium molybdate and 0.5 ml of stannous chloride were further added to this sample and it was allowed to stand for 10 minutes to develop color. After this the reading was taken (APHA).

3.6.7 Total organic carbon

Total organic carbon (TOC) is the amount of carbon found in an organic compound and is often used as a non-specific indicator of water quality or cleanliness of pharmaceutical manufacturing equipment. TOC may also refer to the amount of organic carbon in soil, or in a geological formation, particularly the source rock for a petroleum play; 2% is a rough minimum. For marine surface sediments, average TOC content is 0.5% in the deep ocean, and 2% along the eastern margins.

A typical analysis for TOC measures both the total carbon present and the so-called “inorganic carbon” (IC), the later representing the content of dissolved carbon dioxide and carbonic acid salts. Subtracting the inorganic carbon from the total carbon yields TOC. Another common variant of TOC analysis involves removing the IC portion first and then measuring the leftover carbon.

A variety of different terms are used to identify the different types of carbon present at different levels of detail.

- Total Carbon (TC) - all the carbon in the sample, including both inorganic and organic carbon
- Total Inorganic Carbon (TIC) - often referred to as inorganic carbon (IC), carbonate, bicarbonate, and dissolved carbon dioxide (CO₂).
- Total Organic Carbon (TOC) - material derived from decaying vegetation, bacterial growth, and metabolic activities of living organisms or chemicals.
- Elemental Carbon (EC) - charcoal, coal, and soot. Resistant to analytical digestion and extraction, EC can be a fraction of either TIC or TOC depending on analytical approach.
- Non-Purgeable Organic Carbon (NPOC) - commonly referred to as TOC; organic carbon remaining in an acidified sample after purging the sample with gas.
- Purgeable (volatile) Organic Compound (VOC) - organic carbon that has

been removed from a neutral, or acidified sample by purging with an inert gas. These are the same compounds referred to as Volatile Organic Compounds (VOC) and usually determined by Purge and Trap Gas Chromatography.

- Dissolved Organic Carbon (DOC) - organic carbon remaining in a sample after filtering the sample, typically using a 0.45 micrometer filter.
- Suspended Organic Carbon - also called particulate organic carbon (POC); the carbon in particulate form that is too large to pass through a filter.

Table 3.1: Set water quality parameters for fresh water in India

Parameters	Recommended range/values			
	Drinking	Domestic use	Irrigation	Aquatic Life
pH	6.5-8.4	6.5-8.5	6.5-8.5	6.5-8.4
Water temp.	--	--	<30° C	3-28° C
TSS	<500mg/l	--	<900mg/l	
Dissolved oxygen	4-6 mg/l	--	--	
Turbidity	<0.5 ntu	--	--	
Nitrates	< 1 mg/l	<50 mg/l	<62mg/l	
Phosphates	--	--	0.05-0.1 mg/l	
Total Carbon	< 4 mg/l	<4 mg/l	--	

(Source : IS 10500-2012)

Chapter-4

RESULTS AND DISCUSSIONS

In this study, hourly meteorological data and LULC maps of the Dal catchment were integrated with a GIS based hydrological model HSPF for determining the water quality status of the Dal lake and simulation of model for long term forecasting of events. The observed data of different water quality parameters was taken from LAWDA, Kashmir. The calibrated results of different water quality parameters were validated and were compared with the set standards of water quality and based on the results obtained changes in management strategies were suggested. The details of evaluation of water quality parameters through GIS and HSPF model are discussed as follows.

4.1 Integration of GIS with hydrologic model (HSPF) to determine water quality of Dal Lake

Three different sites of Dal Lake were selected in the catchment for calibrating the water quality parameters. The sites selected were Hazratbal, Gagribal and Telbal, and were numbered as Site 1, 2 and 3 respectively.

The results for different water quality parameters were calibrated and validated using HSPF. The input parameters for HSPF i.e. LULC, point sources, basin layer and stream cover maps were produced by digitizing the satellite imagery of the catchment area for the year 2013. The image was a LISS IV image for the month of October, 2013. Arc GIS 10.2 was used to produce the above mentioned maps, Fig. 4.1, 4.2, 4.3 and 4.4 show the LULC of Dal catchment, point sources of pollution in Dal Lake, Sub-Basin and stream cover of the catchment respectively.

The results calibrated and validated for different water quality parameters at the selected 3 sites are as follows:-

4.1.1 Water temperature

Monthly water temperature fluctuation results are presented in Fig.4.5-4.7 for comparison of observed data for the layer 1 (located at a depth of 20 cm from the surface) and the predicted water temperature for the layer 6 (located at a depth of

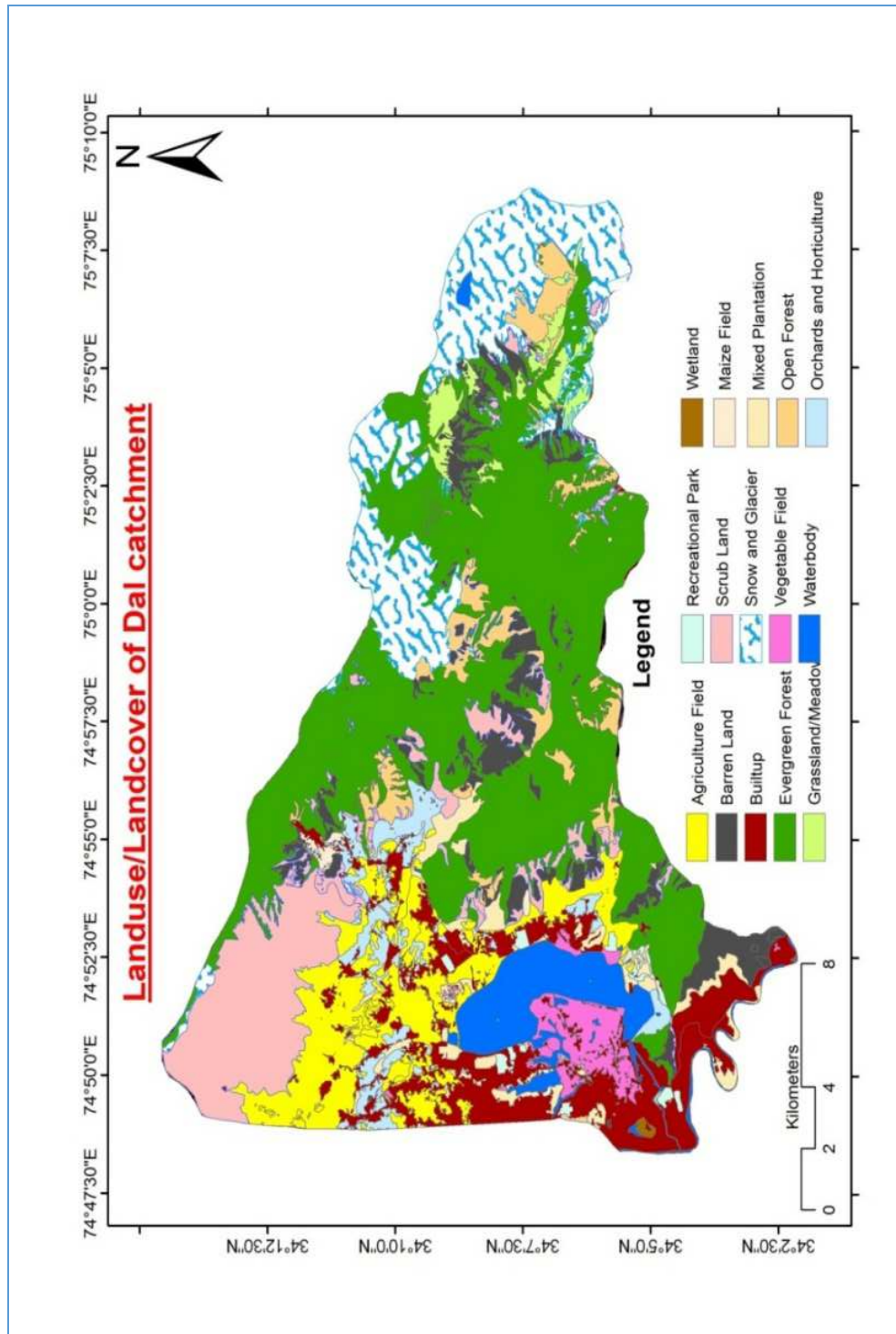


Fig. 4.1: LULC map of Dal catchment for the year 2013

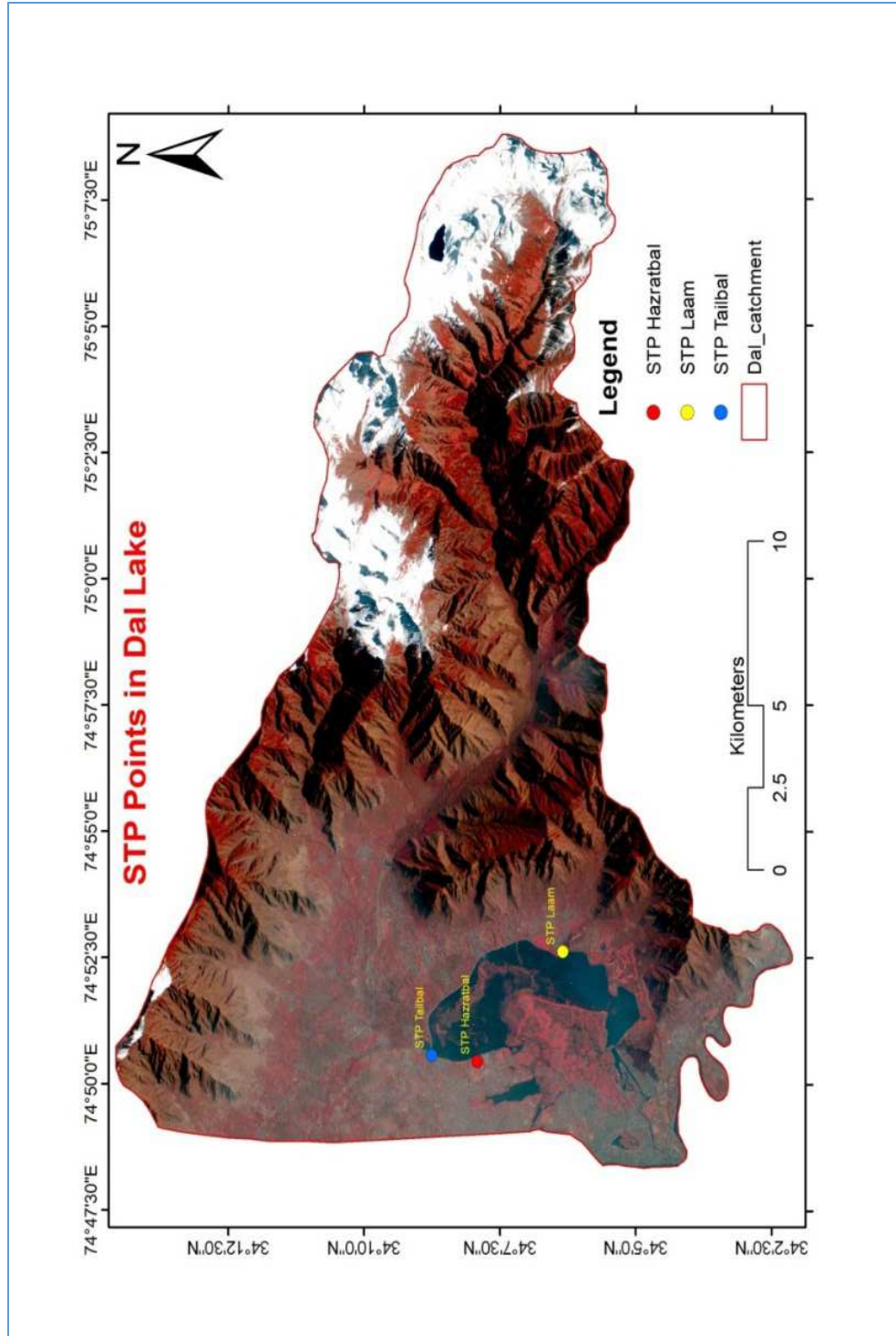


Fig. 4.2: Point sources of pollution in Dal catchment

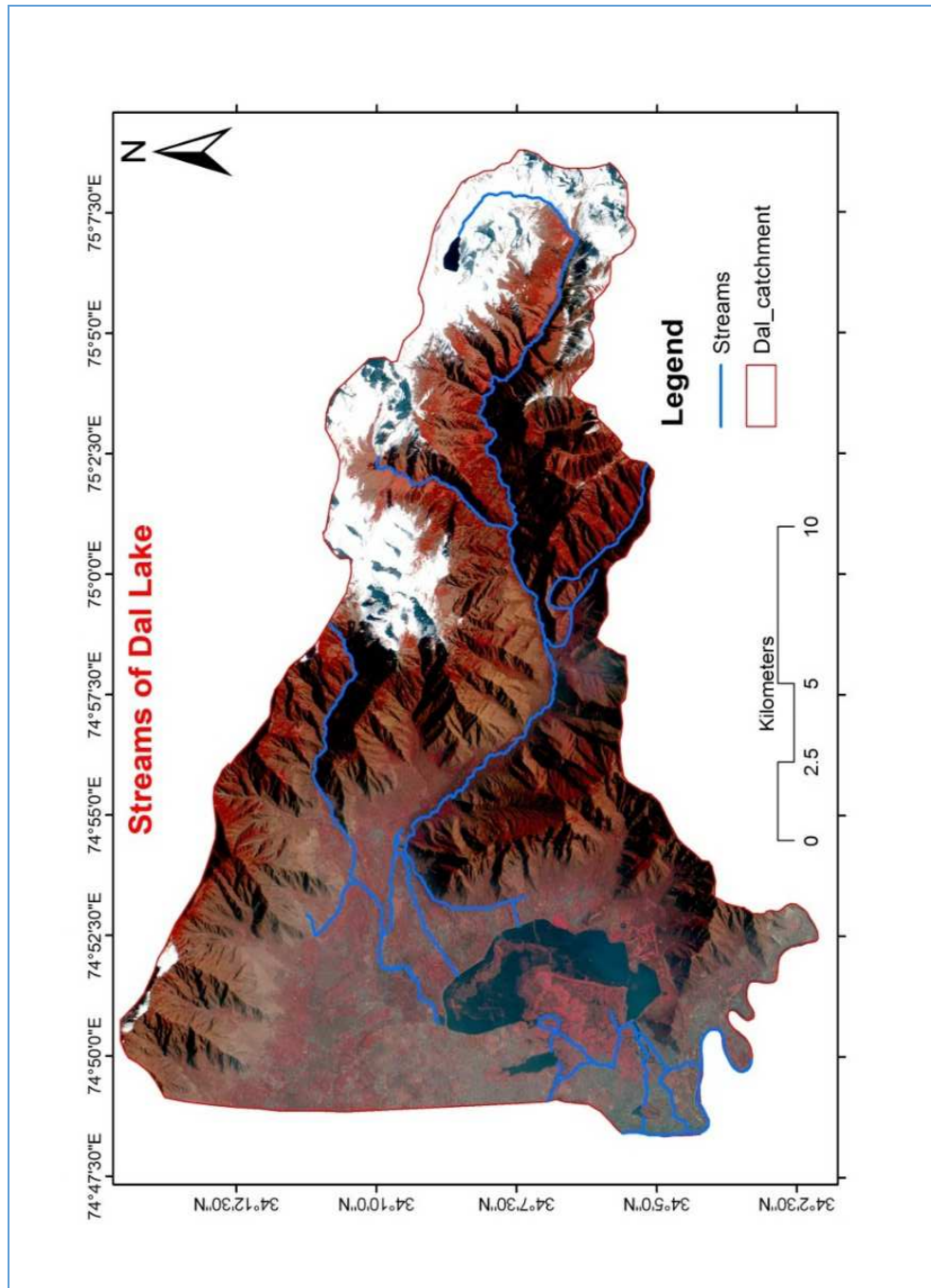


Fig. 4.3: Stream cover of the Dal Catchment

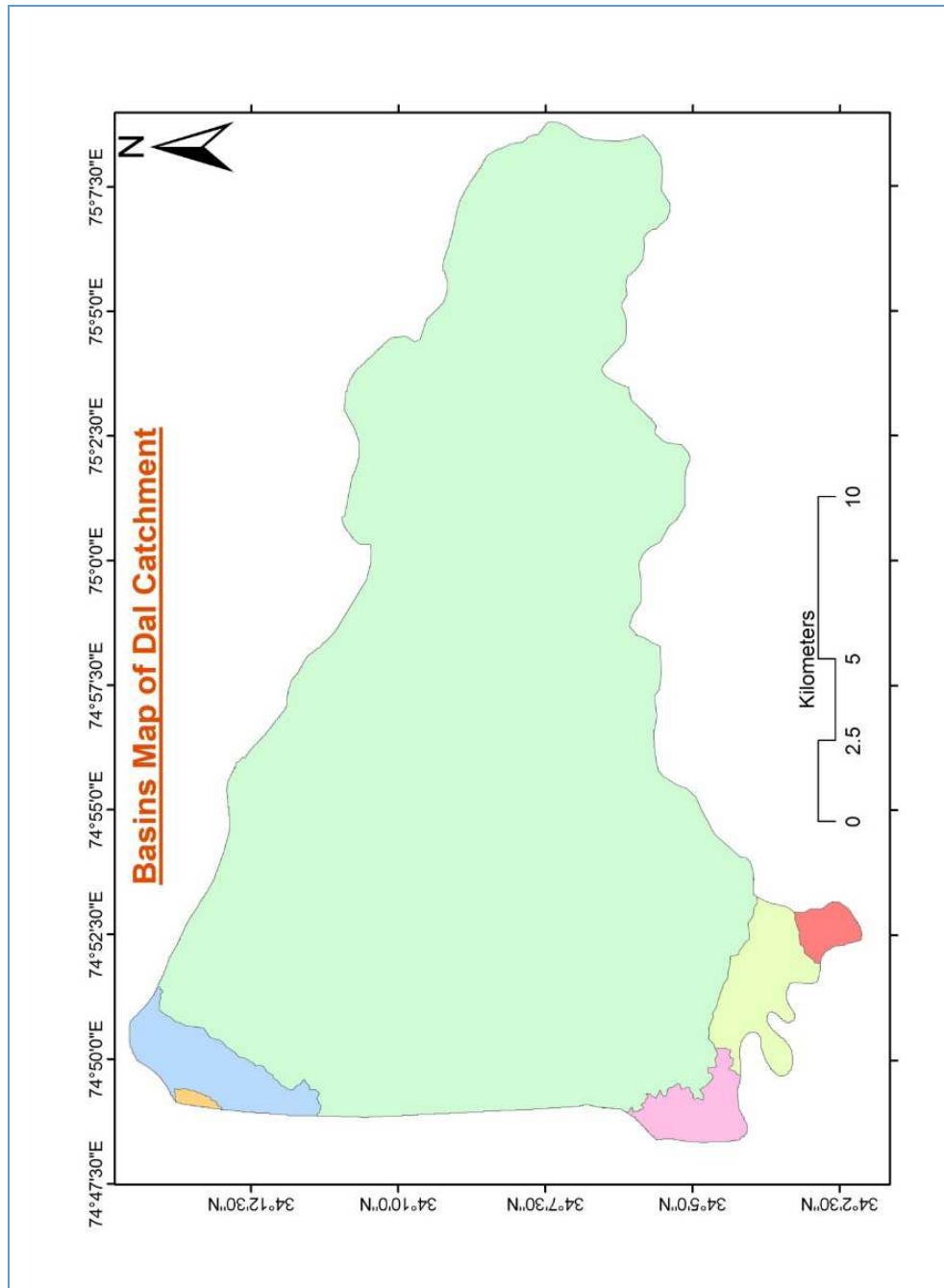


Fig. 4.4: Sub-basins layer of the Dal Catchment

60cm from the surface). The observed water temperature at layer 1 for all the three sites was found in the range of 2-29°C, with the highest temperature rising in the months of July-August during the year 2012.

The simulated water temperatures at the 3 sites ranged from 4-28°C which is in optimum range for aquatic life as well as irrigation. The water temperature at layer 6 was predicted to range from 2.5-18°C, 2.4-22°C and 1.5-25°C at sites 1, 2 and 3 respectively.

The validation results of the calibrated water temperature for the period of April 2012 to April 2013 with the observed data for the period one year starting from May 2013 to May 2014 gave regression coefficients $R^2 = 0.643, 0.732$ and 0.66 for site 1,2 and 3 respectively.

The water temperature followed air temperature rather closely as is common for small bodies of water (Khan *et al.*, 2014). A same trend in the water temperatures of the Dal Lake was found by Khan *et al.* (2014) with the water temperature observed to range between 6 and 18°C and Mushtaq *et al.* (2013) observed the water temperature to range between 4 and 28°C.

4.1.2 Total Suspended Solids (TSS)

The observed TSS values at layer 1 were found to range between 10-20 mg/l and at sites 2 and 3, between 25 and 80 mg/l with a slight rise during the months when precipitation was recorded (i.e. July and September, 2012).

The simulated values for TSS at site 2, layer 1 were found to range from 14-62 mg/l. The TSS values were found to be higher in layer 6 with maximum TSS going upto 200 mg/l. This might be due to the fact that suspended solids are heavier and thus accumulate more at the lower layers. Fig. 4.8 shows the TSS values at site 2.

The simulated values for TSS at site 3, layer 1 ranged between 8 and 820 mg/l, whereas the TSS values in layer 6 were found to range from 10-1000 mg/l with higher values of TSS recorded in the period of rainfall because of the presence of sediments and soil particles in higher concentration in the run of waters that flow from the catchment into the lake. Fig. 4.9 shows the TSS values at site 3.



Fig. 4.5: Observed and simulated water temperature at Site 1 (Hazratbal)



Fig. 4.6: Observed and simulated water temperature at Site 2 (Gagribal)

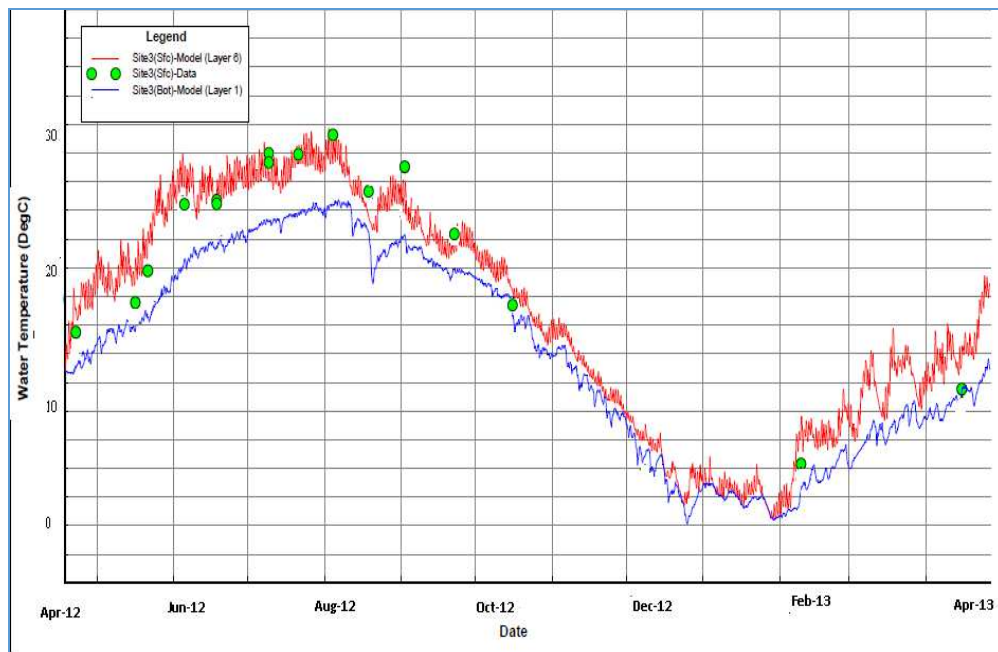


Fig. 4.7: Observed and simulated water temperature at Site 3 (Telbal)

The simulated values were then validated with the observed TSS for the time period May 2013 to May 2014 and gave a regression coefficient of $R^2 = 0.447$ and 0.843 for site 2 and 3 respectively (Figs. 4.10 and 4.11).

4.1.3 Turbidity

Turbidity is calculated on the basis of the following equation:

$$\text{Turbidity} = 1.4247 \times \text{TSS} - 2.1084 \quad (\text{Eq. 4.1})$$

Turbidity simulation results (Fig. 4.12 and 4.13) have shown that the turbidity ranges from 0.4-80 ntu and 25-1000 ntu at site 2 and 3 respectively which exceeds the permissible limit of turbidity i.e. 25 ntu. Since the calibrated results of turbidity are calculated from the model results of TSS therefore, the overestimate of TSS for the storm of August-September 2012 results in the overestimate of turbidity for the same period.

The regression relationship between calibrated TSS and turbidity gives a regression coefficient $R^2 = 0.73$ (Fig. 4.14).

4.1.4 Dissolved Oxygen (DO)

The observed values of Dissolved Oxygen (DO) values at layer 1 were found to be in the range 7-11 mg/l, 5-12 mg/l and 5-11 mg/l at Site 1, 2 and 3 respectively. The higher values of DO were observed in the months from October 2012- March 2013.

The simulated results have shown the DO values at layer1 to range from 5.8-12.2mg/l, 5-12mg/l and 6-13mg/l at Sites 1, 2 and 3 respectively. While, the simulated results for DO at layer 6 for Sites 1, 2 and 3 ranged between 0.5-12.2 mg/l, 0-12 mg/l and 1.8- 13 mg/l (Figs. 4.15-4.17). The DO values thus obtained are all in compliance with the water quality criteria for the epilimnion under stratified conditions.

It can be seen in these model-data plots Fig. 4.15, 4.16 and 4.17, the model results for both the surface and bottom layer are in very good agreement with measured oxygen. The exception is the period characterized by super saturated oxygen conditions that were observed in the surface layer during July 2012 at Site 1. Similar super saturated oxygen conditions were also observed, and not matched

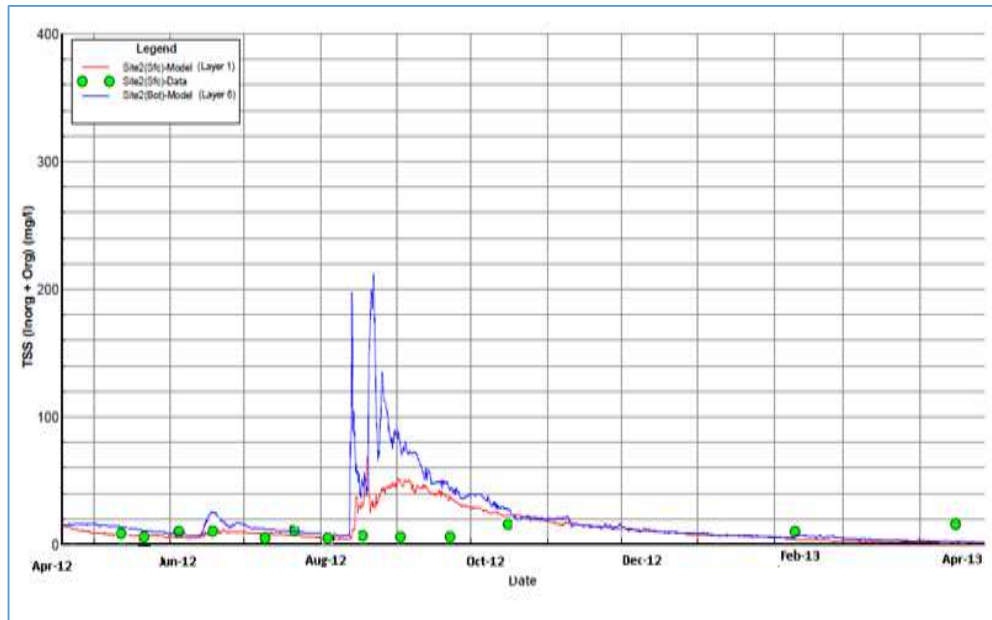


Fig. 4.8: Observed and simulated TSS at Site 2 (Gagribal)

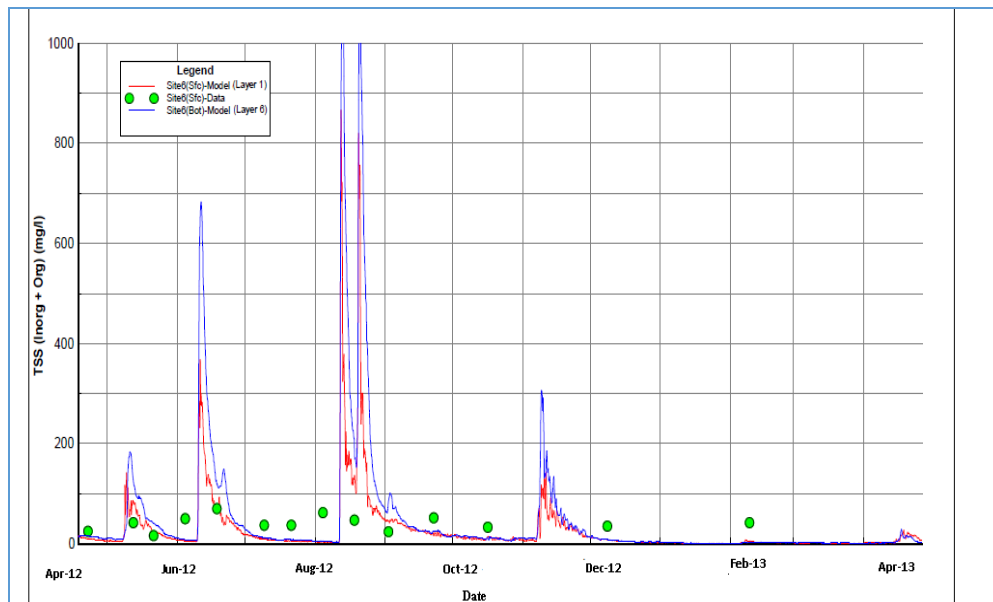


Fig. 4.9: Observed and simulated TSS at Site 3 (Telbal)

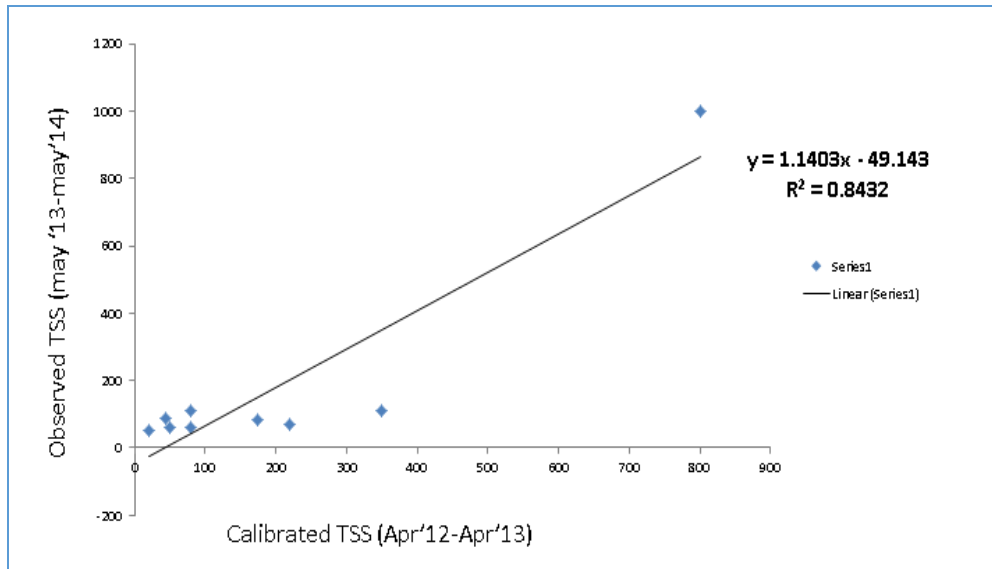


Fig. 4.10: Validation results for TSS at site 2

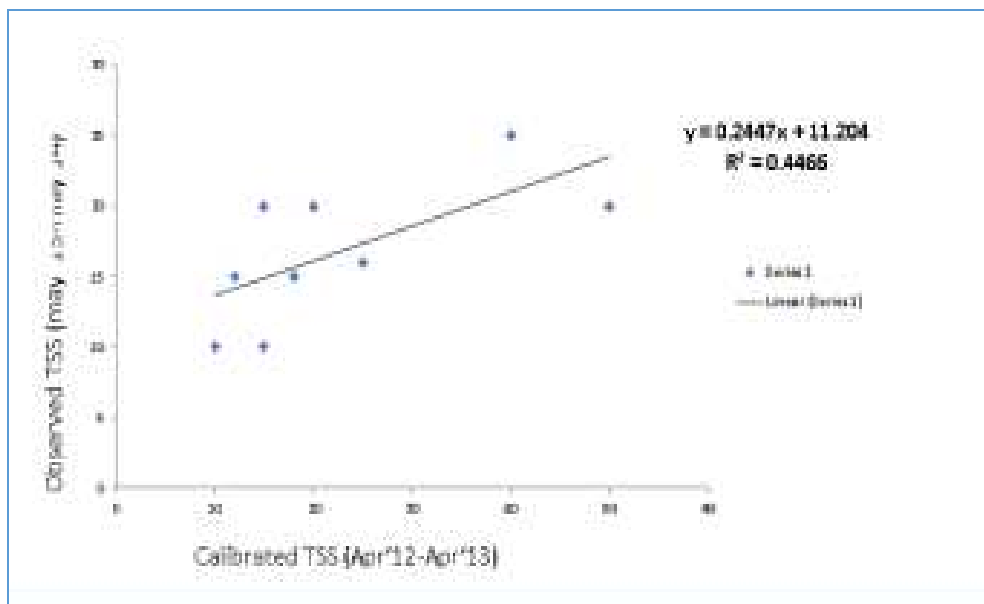


Fig. 4.11: Validation results for TSS at site 3

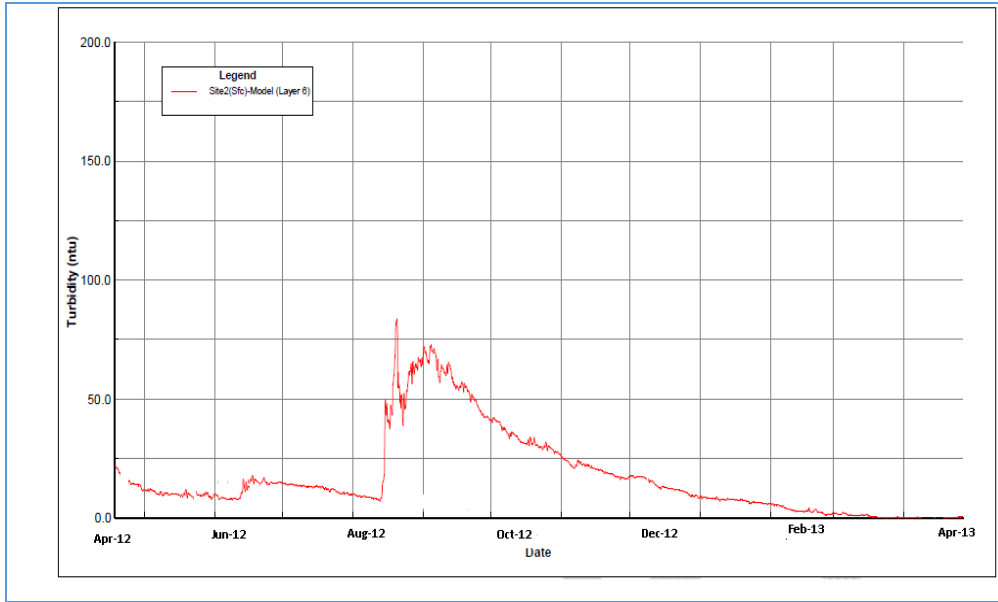


Fig. 4.12: Simulated Turbidity at Site 2 (Gagribal)

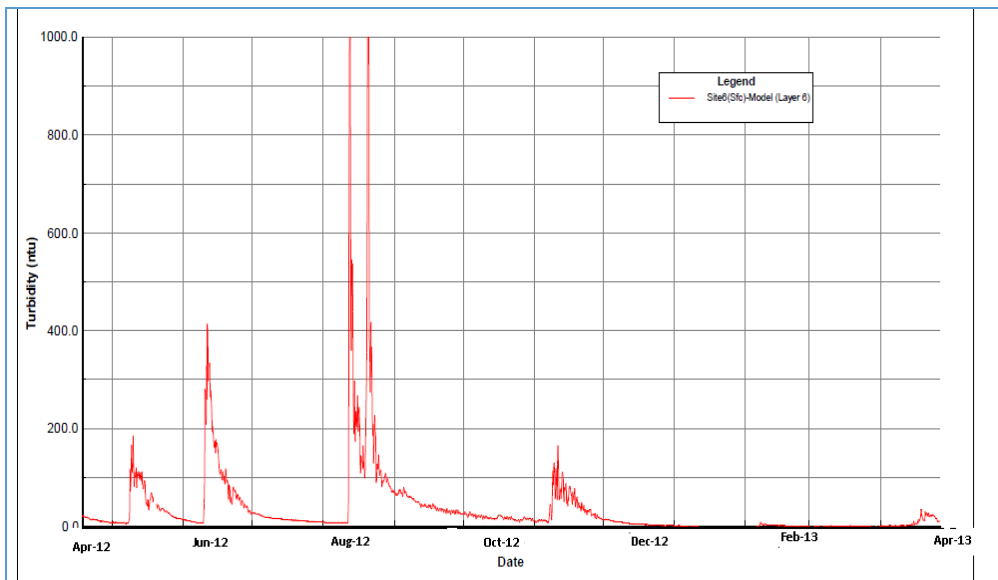


Fig. 4.13: Simulated Turbidity at Site 3 (Telbal)

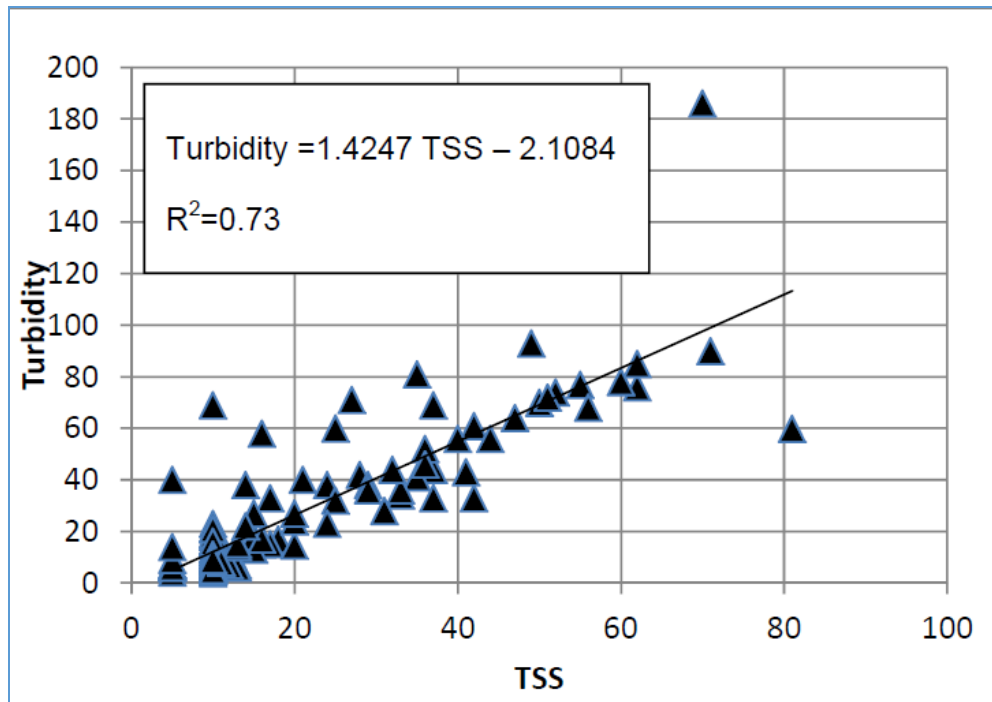


Fig. 4.14: Regression relationship between TSS and Turbidity

by the model, at the layer 1 of Sites 2 and 3. The most notable thing about the model results is that surface and bottom layer oxygen results at Site 2 clearly show the hydrodynamic impact of increased mixing that resulted from the storm events in August 2012. Water column stratification was eroded and the water column became well mixed with only a very small gradient between bottom layer and surface layer oxygen. When the water column restratified in September bottom oxygen was once again reduced to anoxic levels less than 2 mg/L that persisted until seasonal stratification was eroded in October.

The validation of the calibrated values of DO for the period April 2012- April 2013 with the observed values of DO for the period May 2013- May 2014 have shown regression coefficients $R^2 = 0.734, 0.732$ and 0.762 for Sites 1, 2 and 3 respectively (Fig. 4.18-4.20).

4.1.5 Total organic carbon (TOC) in Dal Lake (surface layer and lacustrine zone)

TOC is the sum of dissolved organic carbon (DOC) and particulate organic carbon (POC). All the three values of organic carbon for surface layer (i.e. layer 1) as well as the lacustrine zone of the Dal Lake were predicted by the model using the LULC map of the area and the meteorological data.

The simulated values of TOC for layer 1 were found to lie between the range of 2.5-8 mg/l and for the lacustrine zone the values predicted ranged between 2-9 mg/l (Fig. 4.21). The simulated values showed an increase in the TOC levels in layer1 during the storm events from Aug-Sep. 2012, while as the TOC levels in the lacustrine zone of the lake showed an increase after the storm event.

The POC values predicted by the model were found to lie between 0.2-1.8 mg/l for layer 1 and 0-1 mg/l for the lacustrine zone (Fig. 4.22). DOC values for layer 1 ranged between 2.2 and 5.8 mg/l and for the lacustrine zone the values were simulated to range from 2.1-7 mg/l (Fig. 4.23). The model-data comparisons for POC and DOC show that DOC is the larger component of TOC. The results for POC and DOC show that the model overestimates POC and underestimates DOC to some extent.

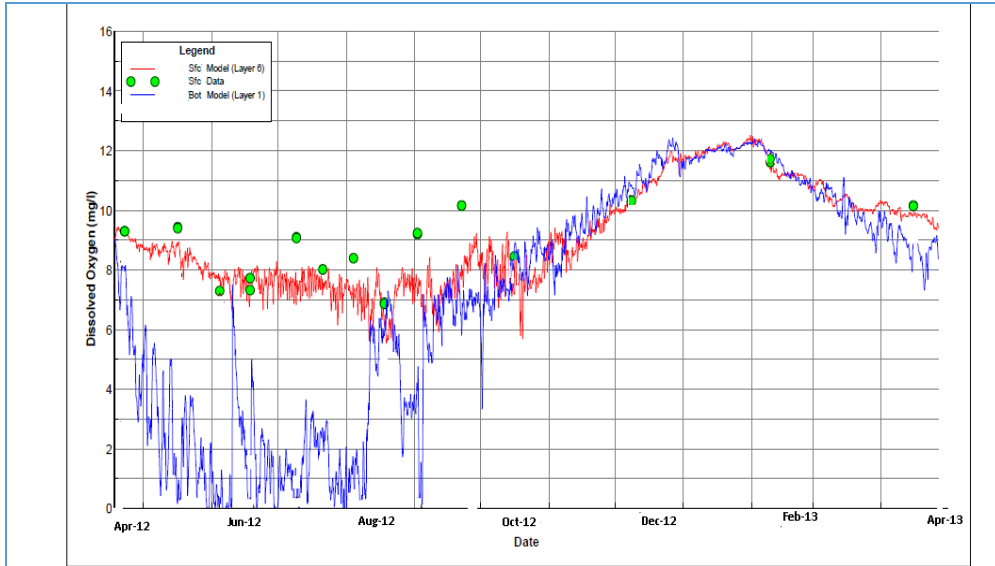


Fig. 4.15: Observed and simulated DO at Site 1 (Hazratbal)

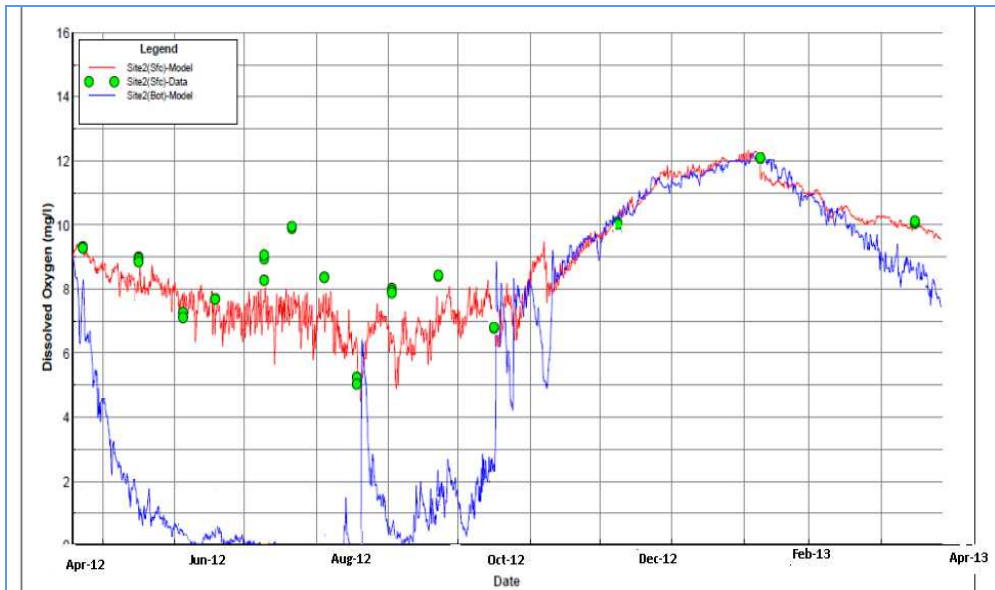


Fig. 4.16: Observed and simulated DO at Site 2 (Gagribal)

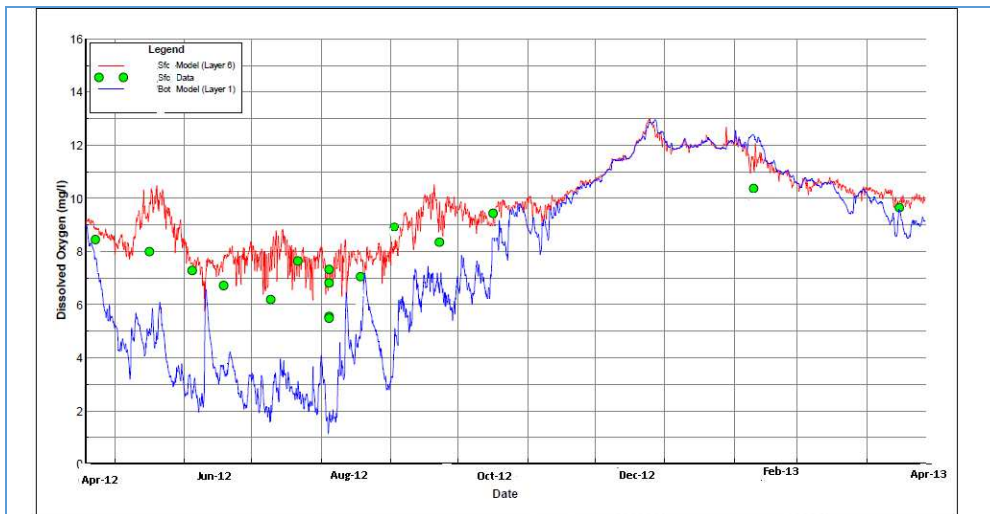


Fig. 4.17: Observed and simulated DO at Site 3 (Telbal)

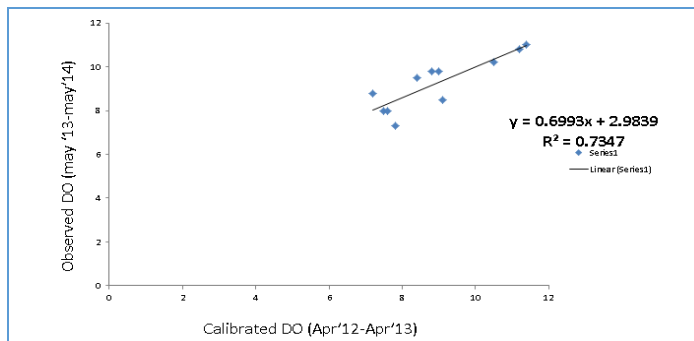


Fig. 4.18: Validation results for DO at Site 1

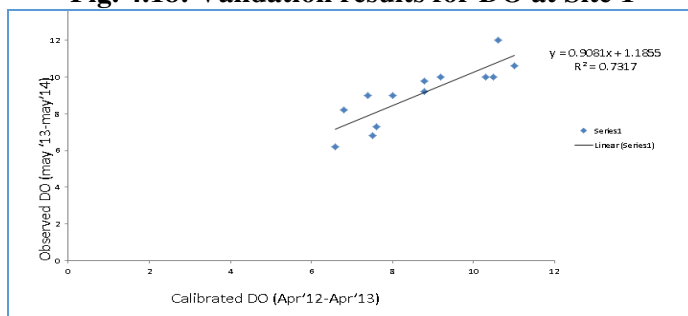


Fig. 4.19: Validation results for DO at Site 2

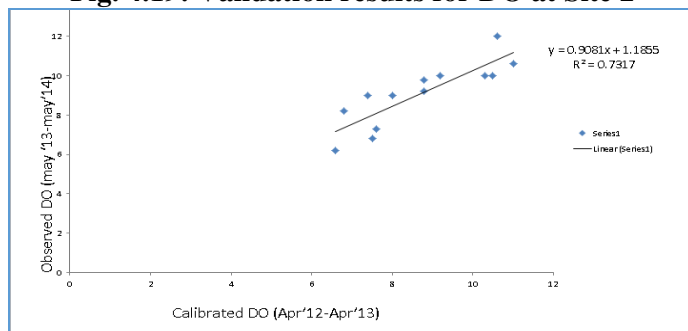


Fig. 4.20: Validation results for DO at Site 3

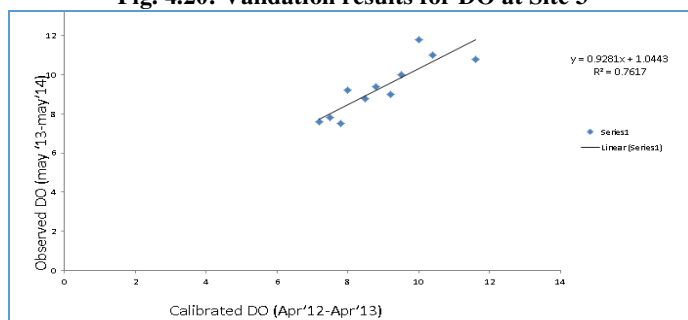


Fig. 4.21: Validation results for DO at Site 3

4.1.6 Nitrogen

Total Nitrogen (TN) consists of Total Organic Nitrogen (TON), Ammonia and Nitrate-Nitrite. All the three values of nitrogen were presented for comparison with the observed data for the surface layer and the lacustrine zone.

The observed values of TON at layer 1 ranged between 0.5-1.38 mg/l while as at lacustrine zone the values were found to range from 0.38-0.68 mg/l. The simulated values for layer 1 and lacustrine zone were found to range from 0.08-0.55 mg/l and 0.05-0.72 mg/l respectively (Fig. 4.24).

The model results then underestimate TON and TN for the late summer-fall (August-October 2012) and the subsequent winter-spring from November 2012 through April 2013 (Figs. 4.25 and 4.26). In the model TN is the sum of TON, ammonia-N and nitrate-N and TON is derived as the sum of detrital Particulate Organic Nitrogen (PON), algal PON and Dissolved Organic Nitrogen (DON). Unlike the dataset for organic carbon, observed data is not available to compare the model results to measured PON and DON. The model-data comparison for inorganic nitrogen is shown for ammonia-N (Fig. 4.27) and nitrate-N (Fig. 4.28). Observed data for bottom layer ammonia shows a sharp increase from relatively low concentrations (~0.05 mg/L) in April-June to much higher concentrations (~0.25-0.6 mg/L) in response to the onset and persistence of anoxia during July-August 2012. Bottom layer ammonia is overestimated in the model in May-June because thermal stratification is initiated in the model somewhat earlier than observed. Bottom oxygen in the model at Site 2 then decreases more rapidly than observed in May (Fig. 4.15) and bottom ammonia increases as a result of the increased benthic flux of ammonia that is triggered by anoxic conditions in the overlying water column (Fig. 4.29). The model results show good agreement with the low levels of ammonia observed during the winter-spring from October-November 2012 through April 2013 (Fig. 4.27). The model-data comparison for nitrate (Fig. 4.28) shows reasonable agreement with both the surface and bottom layer observations with the model tracking the initial increase and decline in nitrate through August 2012. The model, although lower than the observed data, reproduces the increase in nitrate beginning in October 2012 with

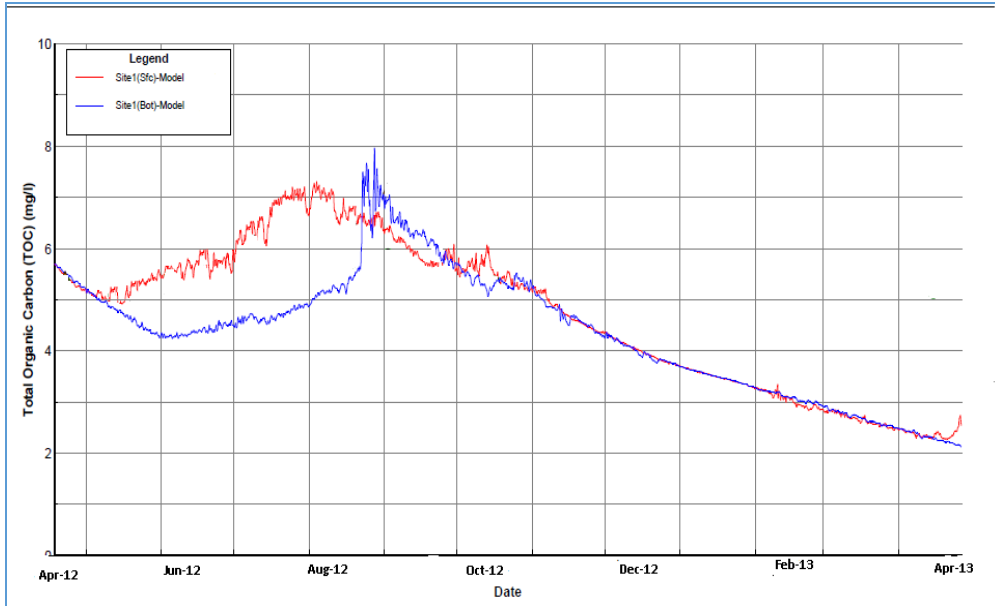


Fig. 4.22: Predicted Total Organic Carbon in Dal Lake

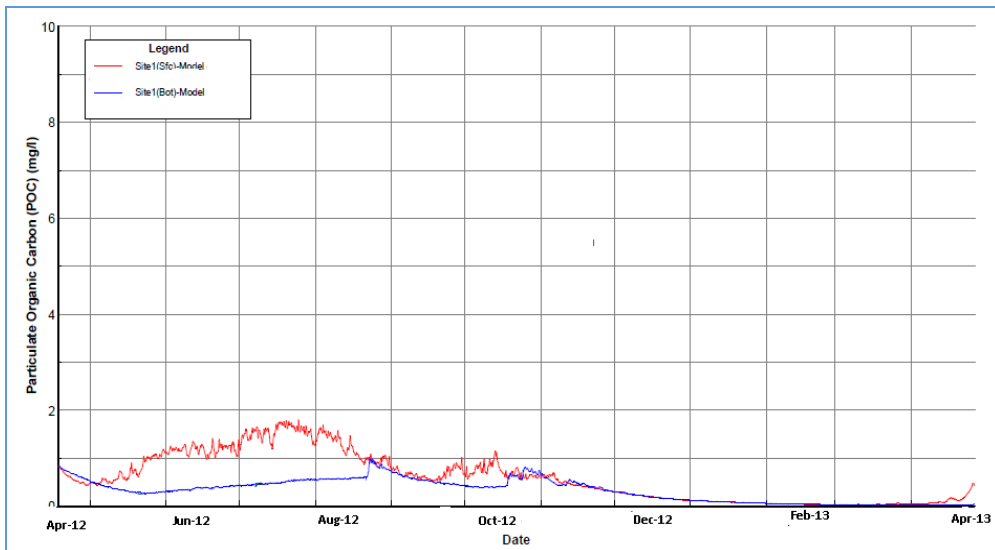


Fig. 4.23: Predicted Particulate Organic Carbon in Dal Lake

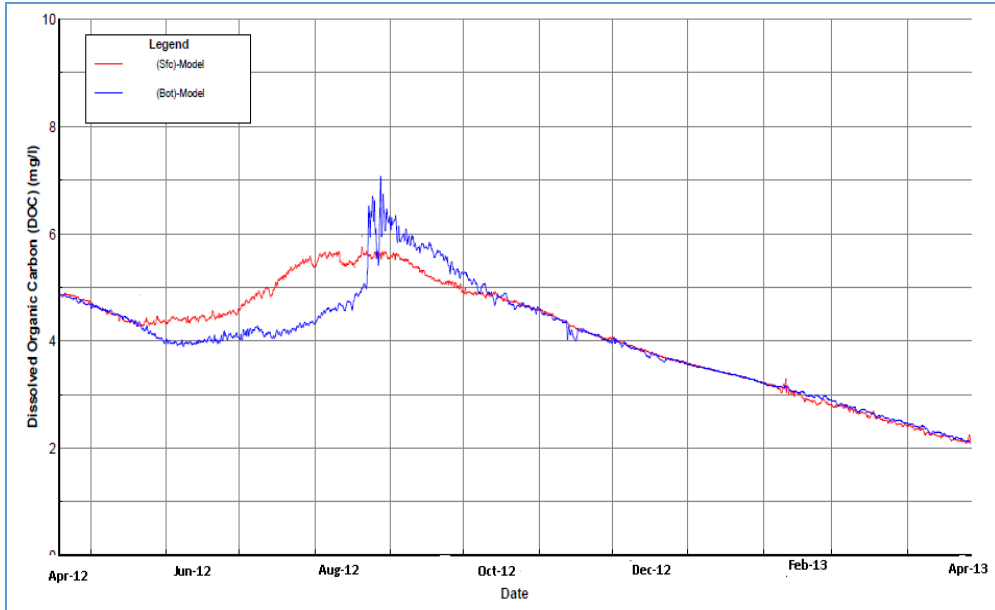


Fig. 4.24: Predicted Dissolved Organic Carbon in Dal Lake

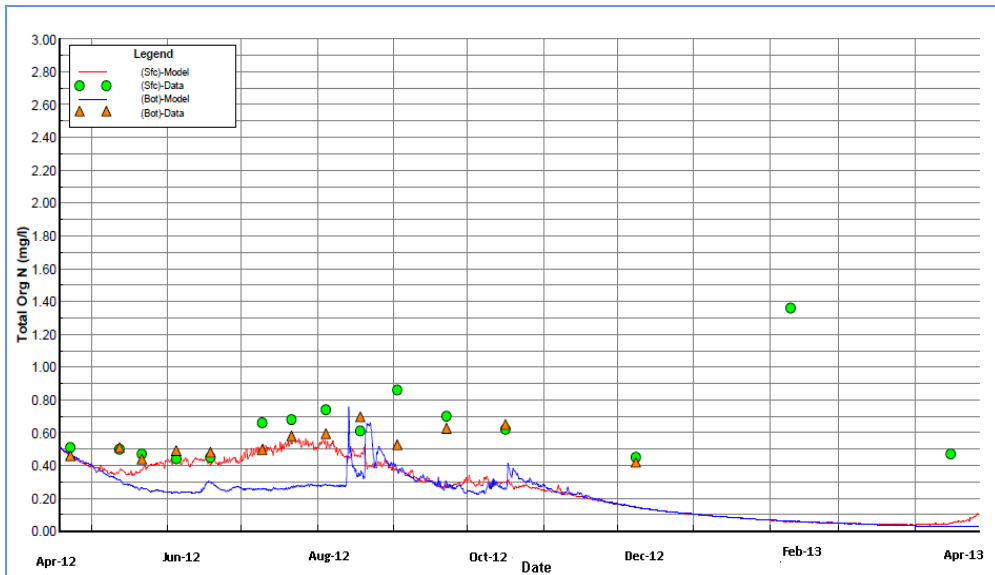


Fig. 4.25: Observed and Simulated Total Nitrogen in Dal Lake

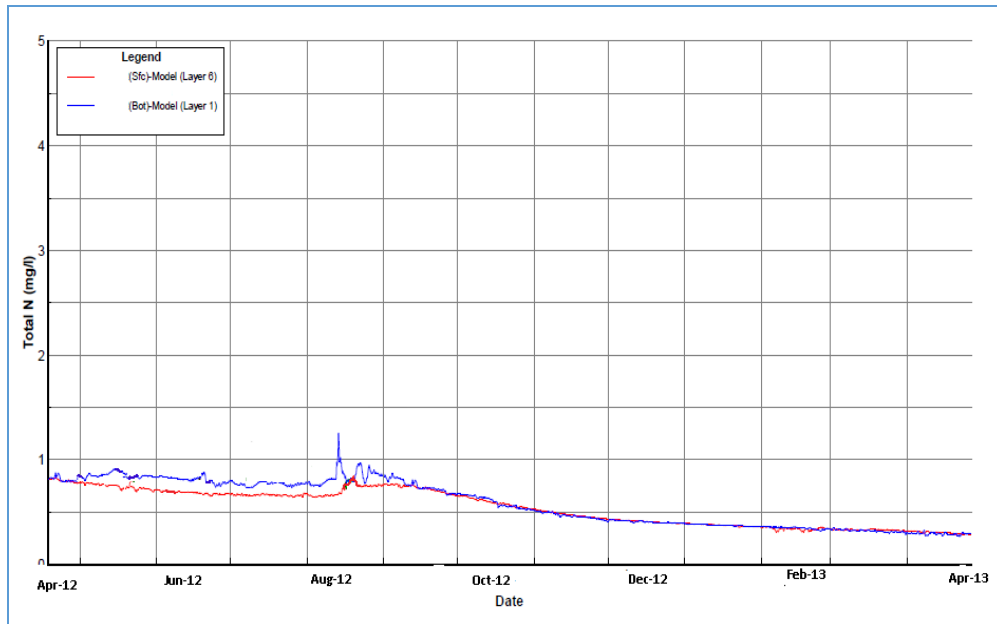


Fig. 4.26: Predicted Total Organic Nitrogen in Dal Lake

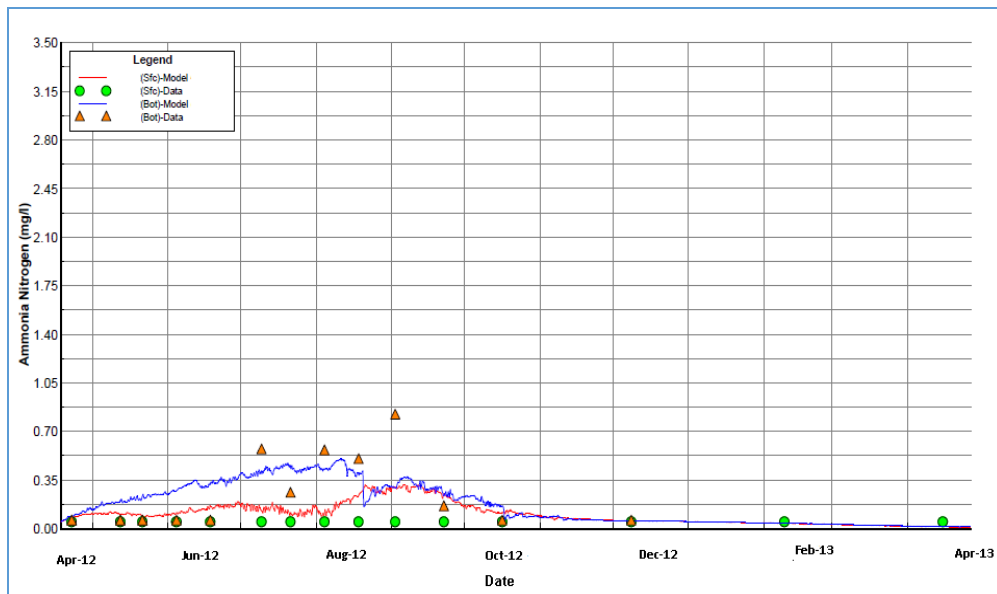


Fig. 4.27: Observed and Simulated Nitrate- Nitrogen in Dal Lake

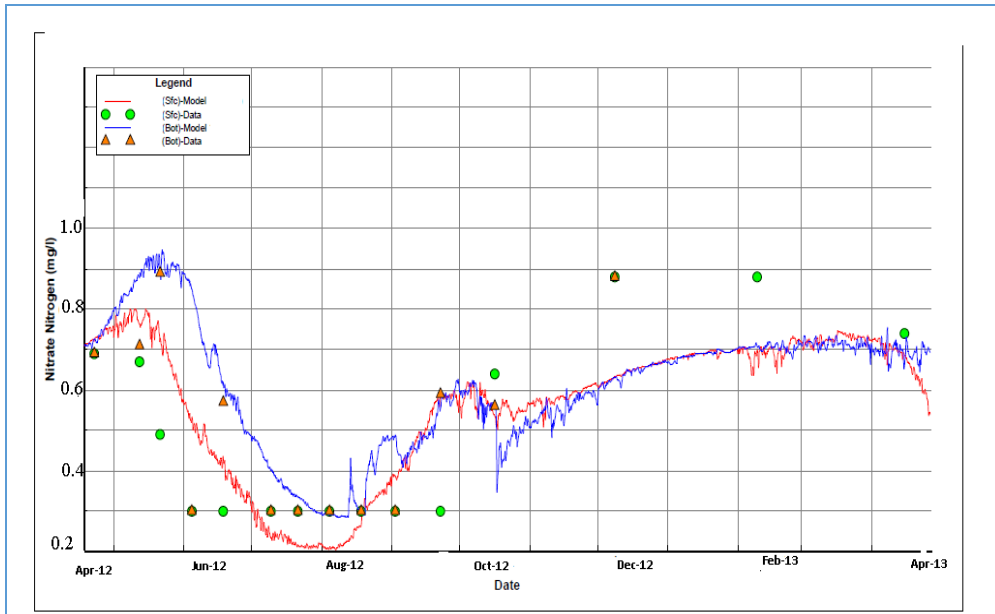


Fig. 4.28: Observed and Simulated Nitrate- Nitrogen in Dal Lake

the transition to a well-mixed water column in the winter-spring.

It was found by the comparison of Ammonia and nitrate flux that the two have a clear relationship as illustrated in Fig. 4.29. Since Ammonia is easily converted into nitrate thus, the lowering of Ammonia results in the increase in nitrate in the sediment bed. The process of nitrification and denitrification is clearly visible and has shown a significant change between the two processes.

The validation of the calibrated values of TON, Ammonia and nitrate-nitrite show a regression coefficient $R^2 = 0.45$, 0.79 and 0.734 respectively (Fig. 4.30-4.32).

4.1.7 Phosphorous

Total Phosphorus (TP), Total Organic Phosphorus (TOP) and total orthophosphate (TPO_4) results are presented for comparison to observed data for the surface layer and lacustrine zone (Fig. 4.33-4.35). As can be seen in the model-data plots shown for Site 2, the model results are in fair agreement with measured TP, TOP and TPO_4 for the bottom layer from April 2012 through August 2012. The model results then overestimate surface and bottom layer TP and TPO_4 beginning in September through the winter-spring into April 2013 (Fig. 4.33 and 4.35). In contrast to TP and TPO_4 , the model results for TOP are in reasonable agreement with the observations from September 2012 through April 2013. In the model TP is the sum of TOP, total phosphate and TOP is derived as the sum of detrital POP, algal POP and DOP. The model-data comparison for total phosphate at Site 2 is shown in Fig. 4.35. Observed data for bottom layer phosphate shows a sharp increase from relatively low concentrations (<0.05 mg/L) in April-June to much higher concentrations (~ 0.1 - 0.2 mg/L) in response to the onset and persistence of anoxia during July-August 2012. As described for ammonia, bottom layer phosphate is overestimated early in the model simulation in May-June because thermal stratification is initiated in the model somewhat earlier than observed and bottom oxygen at Site 2 in the model then decreases more rapidly than was observed in May (Fig. 4.15). Bottom phosphate then increases as a result of the increased benthic flux of dissolved phosphate that is triggered by anoxic conditions in the overlying water column. Following erosion

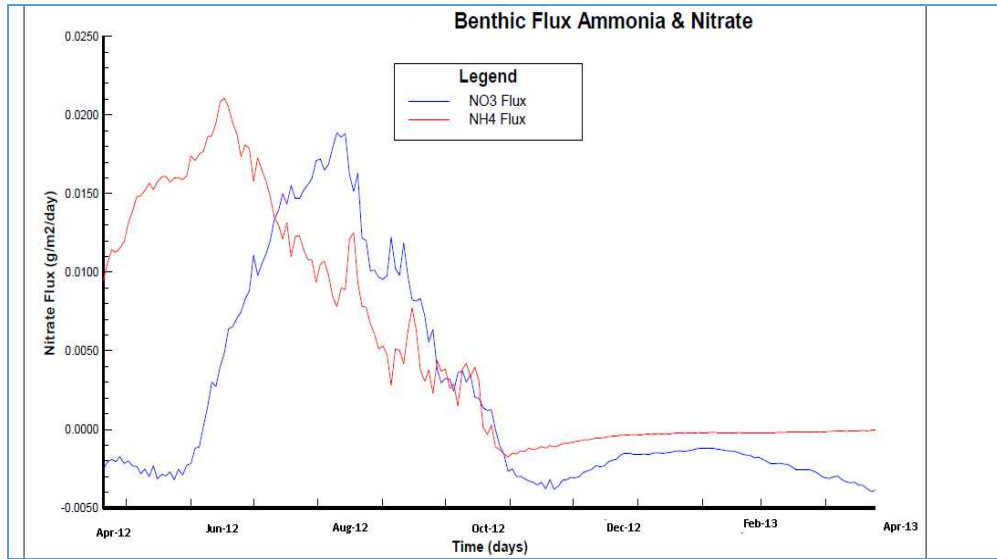


Fig. 4.29: Benthic flux of Ammonia and Nitrate calibration results in the lacustrine zone of Dal Lake

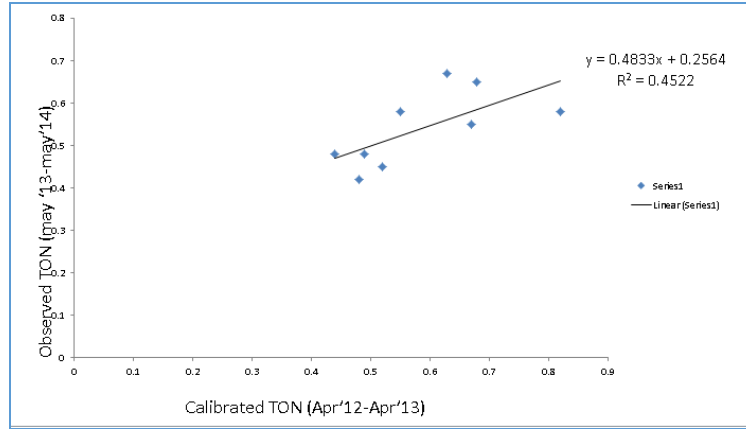


Fig. 4.30: Validation results for TON in Dal Lake

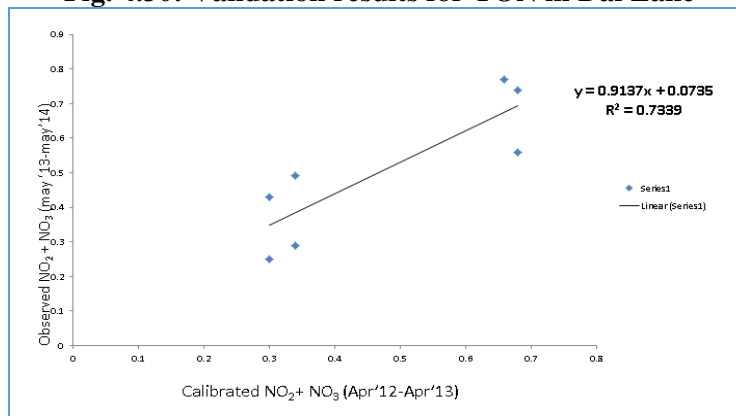


Fig. 4.31: Validation results for nitrate in Dal Lake

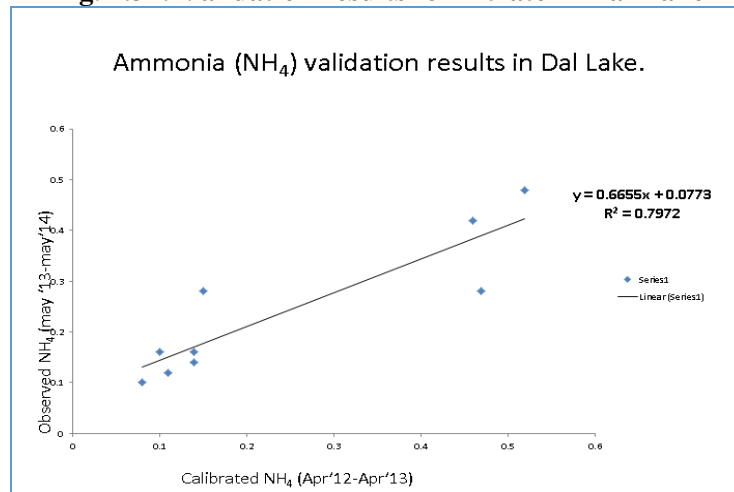


Fig. 4.32: Validation results for nitrate in Dal Lake

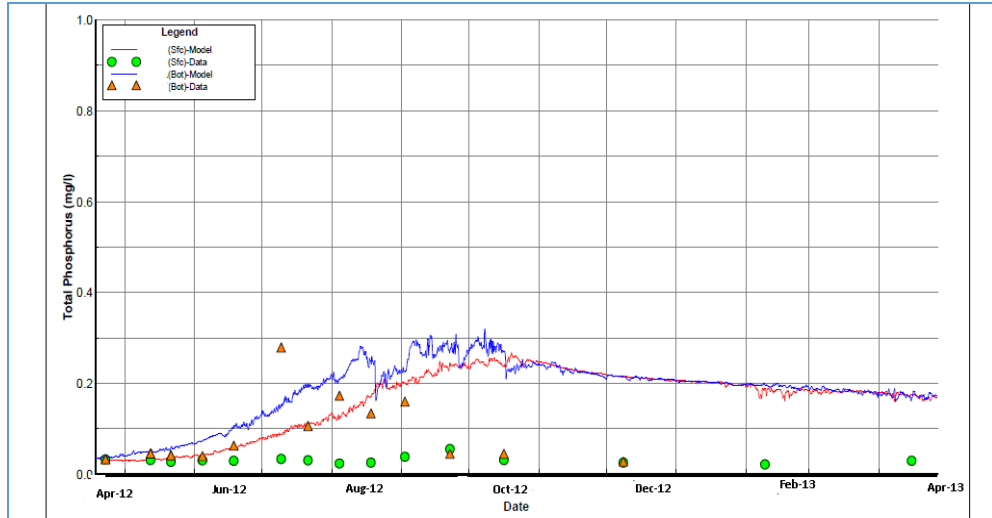


Fig. 4.33 Observed and Simulated Total Phosphorous in Dal Lake

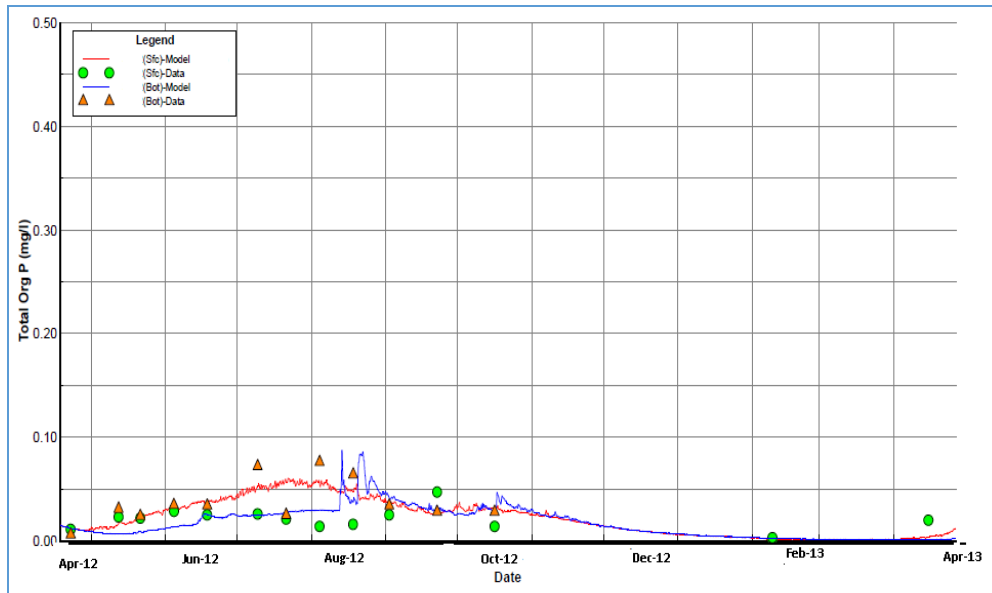


Fig. 4.34: Observed and Simulated Total Organic Phosphorous in Dal Lake

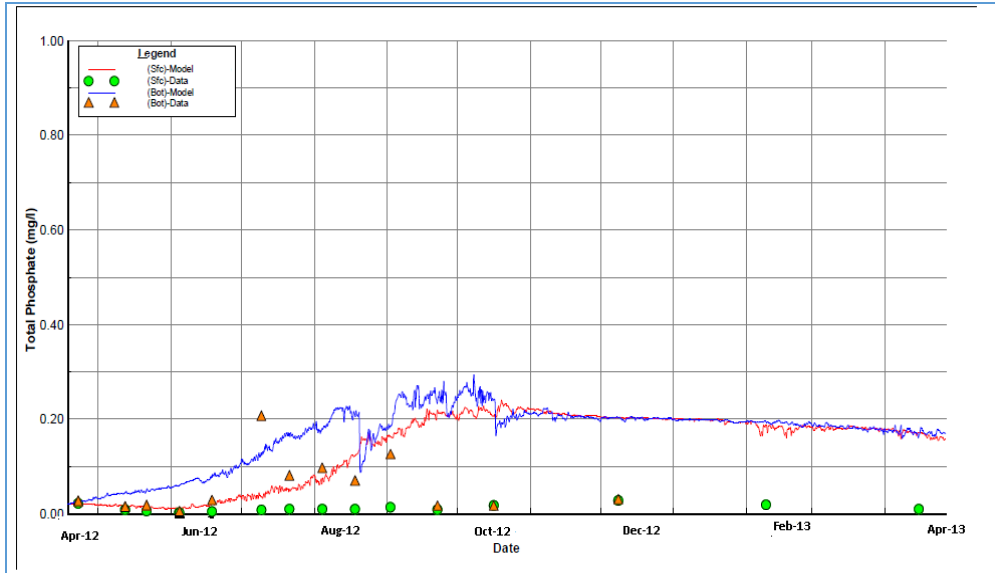


Fig. 4.35: Observed and Simulated Total Phosphate in Dal Lake

of the thermocline, the model results show poor agreement with the low levels of TP and phosphate observed during the winter-spring from October-November 2012 through April 2013 (Fig. 4.33 and 4.35). As long as bottom water oxygen is above hypoxic concentrations (i.e., >2 mg/L), phosphate remains strongly sorbed to an iron oxy-hydroxide precipitate and the release of dissolved phosphate via diffusion from pore-water is prevented. As the near bottom oxygen concentration decreases to anoxic conditions under stratified conditions, however, the redox potential is lowered, iron oxy-hydroxide is reduced to a soluble form of iron, phosphate is no longer sorbed and dissolved phosphate is released from the sediment bed to the overlying water column (Di & Dominic, 2001). Environmental variables that appear to control the release of dissolved phosphate from the sediment bed under stratified hypoxic conditions in a lake are (a) abiotic processes related to bottom water temperature, overlying water dissolved oxygen level, pH, sediment bed composition and the redox potential and (b) biotic processes related to microbial activity (Nowlin *et al.*, 2005). Hupfer and Lewandowski (2008) present a thorough review of the literature related to phosphorus release from the sediment bed, including experiments related to artificial aeration of the hypolimnion. They summarize how phosphorus release is controlled by many factors other than low oxygen concentration in the overlying water column. Hupfer and Lewandowski state that “P-release is controlled by a complex coupling of sediment composition, external load, catchment hydrology, lake morphometry and biogeochemical reactions”. In the model, bottom layer phosphate is dependent on sorption/desorption with cohesive solids and the sediment bed release of phosphate. The benthic flux of phosphate from the sediment bed, in turn, is controlled by production of phosphate from mineralization (decay) of organic phosphorus in the bed, burial loss of organic phosphorus to an inactive sediment layer and sorption/desorption of phosphate with sediment bed solids. Mineralization of organic phosphorus is temperature dependent, burial of organic matter is a constant loss and sorption is dependent on the oxygen concentration of the overlying water via a functional dependence of the partition coefficient on bottom layer oxygen. Adjustable model parameters that control the release of sediment bed phosphate are the mineralization rate for

organic phosphorus, the phosphate partition coefficient, the critical oxygen concentration that triggers the release of phosphate and an “enhancement factor” for partitioning. The enhancement factor, combined with a functional term that incorporates the ratio of the overlying oxygen concentration to the critical oxygen concentration, smoothly reduces the phosphate partition coefficient as overlying oxygen approaches zero. As the partition coefficient is decreased under anoxic conditions, the proportion of dissolved phosphate in the bed is increased, the sediment-water diffusive flux of phosphate is increased and phosphate in the bottom layer of the water column is increased. As noted by Di & Dominic(2001), the mineralization rate and the critical oxygen concentration for sorption were typically not adjusted in several sediment flux modeling studies. A review of the calibrated values of the phosphate partition coefficient and the enhancement factor used in the different studies, however, showed that the range of values assigned for these two parameters was extreme. Combinations of the partition coefficient and the enhancement factor were systematically adjusted during calibration of the Lake Thunderbird model to obtain as good a match to the observed data as was possible. If the phosphate partition parameters were assigned large values to trap phosphate in the bed and suppress benthic phosphate release to match the low bottom water phosphate observed after stratification ended in October, observed high phosphate concentrations during the summer. Conversely, if the parameters were assigned smaller values to increase benthic phosphate release to match the high bottom water phosphate observed during the anoxic period then modeled phosphate concentrations were higher than observed during the fall-winter.

The comparison of benthic flux of Phosphate at the sediment beds of site 1, 2 and 3 is shown in Fig. 4.36. Highest amount of phosphate is recorded after the storm event of August- September 2012 due to the inflow of nutrients with the runoff water. During the months April- July 2012 highest amount of phosphates is seen at Site 3 where more agricultural fields were found, whereas during the storm event highest amount of phosphate was found at Site 1 (Hazratbal) and lowest was recorded at Site 2 (Gagribal).

The validation of the calibrated values of TP, TOP and Total phosphate show a regression coefficient $R^2 = 0.855$, 0.612 and 0.833 (Fig. 4.37-4.39) respectively with the observed values for the period May 2013- May 2014.

4.2 Comparison of results obtained with set standards of water quality

The results obtained for the different nutrients were then compared with the set standards of water quality to determine whether the water of the lake is suitable for irrigation, aquatic life, domestic use and drinking.

The Table 4.1 shows comparison of the obtained results with the set standard of water quality for different purposes.

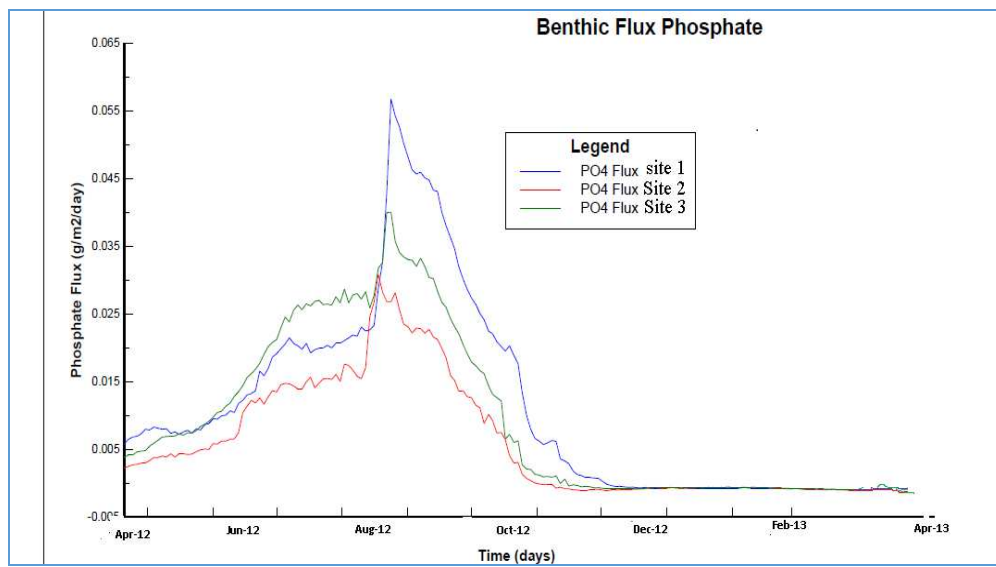


Fig. 4.36: Sediment flux of Phosphate (PO₄) (g/m²/day) comparison in layer 1 at Site 1, Site 2 and Site 3

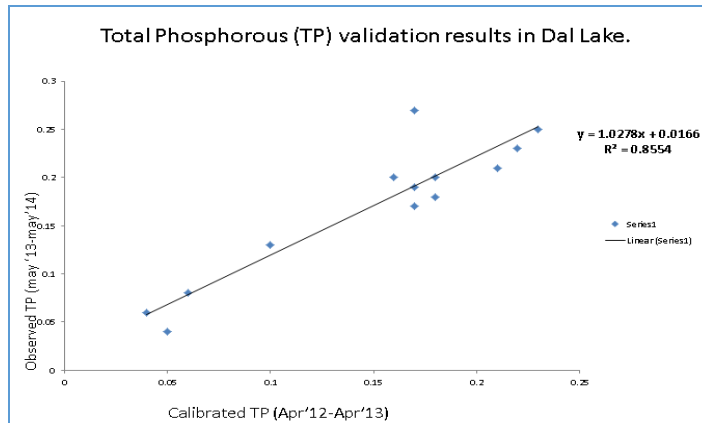


Fig. 4.37: Validation results for TP in Dal Lake

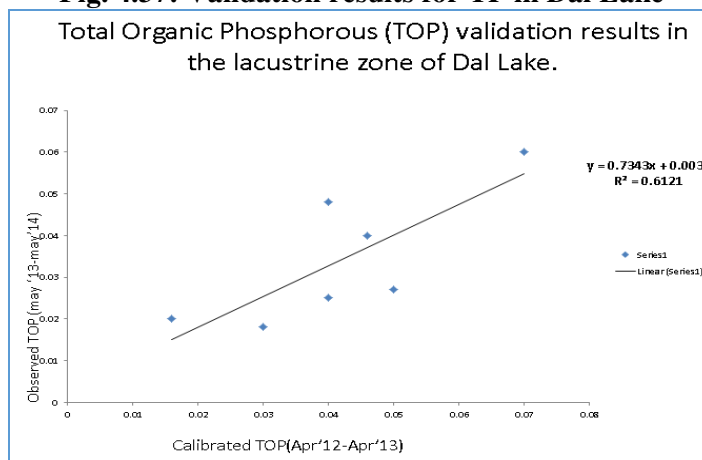


Fig. 4.38: Validation results for TOP in Dal Lake

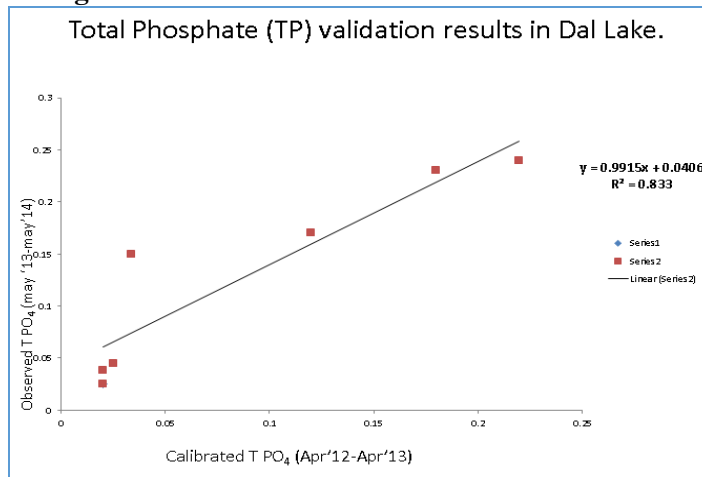


Fig. 4.39: Validation results for TOP in Dal Lake

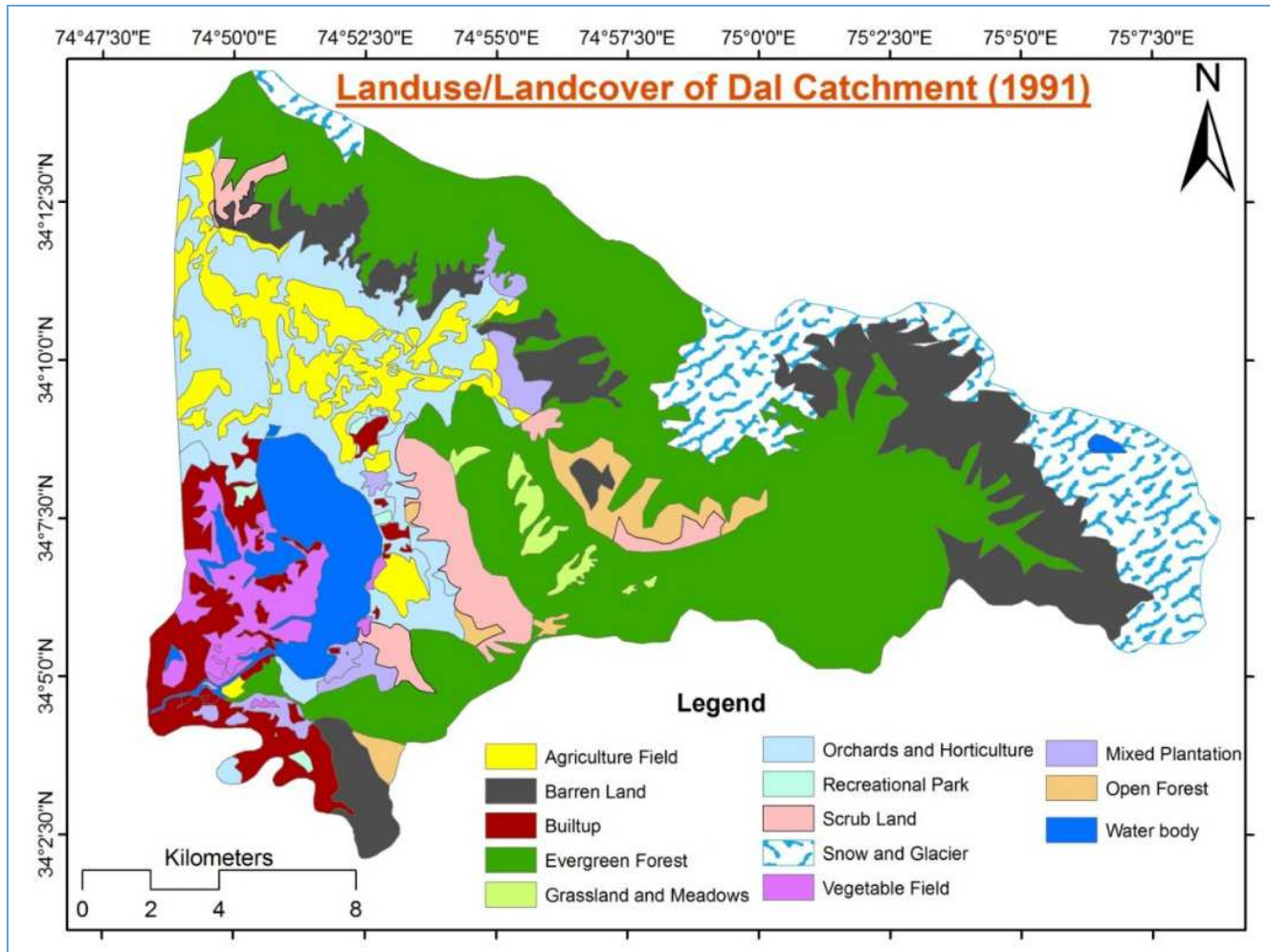


Fig. 4.40: LULC map of Dal catchment for the year 1991

Table 4.1: Comparison of results obtained with set standard of water quality

Parameters	Recommended range/values				Simulated	Observed (LAWDA)
	Drinking	Domestic use	Irrigation	Aquatic life		
pH	6.5-8.4	6.5-8.5	6.5-8.5	6.5-9	--	7.3-8.7
Water temp.	--	--	<30° C	2-26° C	2-28° C	3-30° C
TSS	<500mg/l	--	<900mg/l	<1000mg/l	200-1000 mg/l	160-980 mg/l
Dissolved oxygen	4-6 mg/l	--	--	>4 mg/l	9-13 mg/l	7-11 mg/l
Turbidity	<0.5 ntu	--	--	--	0.2-75 ntu	--
Nitrates	< 1 mg/l	<50 mg/l	<62mg/l	<1.2 mg/l	0.2-1.0 mg/l	0.3-0.9 mg/l
Phosphates	--	--	0.05-0.1 mg/l	< 0.1 mg/l	.001-.08 mg/l	0.02-0.05mg/l
Total Carbon	< 4 mg/l	<4 mg/l	Not recommended	-	3.4-6.5 mg/l	--

(Source : IS 10500-2012)

The water quality parameters comparison shows that the water is suitable for irrigation as well as aquatic life but due to the presence of coliform bacteria (Saleem *et al.*, 2013) it isn't suitable for drinking.

4.3 Determination of management strategies in the catchment area

The land use land cover maps for the study area for the years 2013 and 1991 were prepared and a total of 13 LULC classes were identified in the LandSat image of the year 1991 (Fig. 4.40) and 15 LULC classes were identified in the LISS-IV image of the year 2013 (Fig. 4.1). The Tables 4.2 and 4.3 show the areas under the different land use classes in km² and Table 4.4 presents the difference in the land use classes.

The comparison of land use classes for the year 1991 and 2013 shows a decrease of 1.15% in agricultural field, 2.28% in barren land, 5.35% in evergreen forests, 6.5% in orchards and horticulture, 0.41% in open forests, 0.15% in grasslands and meadows and 0.72% in waterbody. However an increase of 7.91% in built up, 2.4% in mixed plantation, 0.62% in recreational park, 1.86% in scrub land and 3.17% in vegetable field was ascertained.

The change detection (Table 4.3) in the catchment area shows increase in un-planned urbanization and decrease in barren land and agriculture and horticulture in the area. Keeping these changes and the concentration of the nutrients in mind the management strategies which is the need of the hour are firstly, use of organic fertilizers should be encouraged in the catchment area and the main area of concern being the areas inside the lake where vegetable gardens are present in abundance. Secondly, the unplanned urbanization of the catchment area should be stopped in order to prevent more pollution entering the lake waters. Thirdly the sewage from hotels, houseboats and the residential houses inside the lake should not be discharged directly into the lake and measures for the proper treatment of the same should be considered.

Table 4.2: Areas under the different land use classes in km² in the year 1991 and 2013

LULC feature	Area (sq. km) (1991)	Area (sq. km) (2013)
Agriculture Field	21.78	17.59
Barren Land	48.19	39.87
Builtup	16.80	45.67
Evergreen Forest	138.17	118.65
Grassland and Meadows	1.63	1.09
Mixed Plantation	6.91	15.67
Open Forest	8.29	6.78
Orchards and Horticulture	38.59	14.83
Recreational Park	0.80	2.33
Scrub Land	14.72	21.49
Snow and Glacier	41.49	44.46
Vegetable Field	10.29	21.84
Water body	17.23	14.6

Table 4.3: Comparison of the per cent area difference in LULC classes of 1991 and 2013

LULC Type	% Area (2013)	% Area (1991)	Change in LULC classes
Agriculture Field	4.82	5.97	-1.15
Barren Land	10.93	13.21	-2.28
Builtup	12.52	4.61	7.91
Evergreen Forest	32.52	37.86	-5.35
Grassland/Meadows	0.30	0.45	-0.15
Mixed Plantation	4.29	1.89	2.40
Open Forest	1.86	2.27	-0.41
Orchards and Horticulture	4.06	10.58	-6.51
Recreational Park	0.64	0.022	0.62
Scrub Land	5.89	4.033	1.86
Snow and Glacier	12.19	11.37	0.81
Vegetable Field	5.99	2.81	3.17
Waterbody	4.00	4.72	-0.72

Chapter-5

SUMMARY AND CONCLUSIONS

The present study was conducted to determine water quality of Dal Lake using GIS and hydrologic model (HSPF) in which hourly meteorological data and LULC of the catchment area were integrated with HSPF. The results obtained were then compared with the set standards of water quality and the results suggested that the water of the lake is feasible for irrigation and aquatic life.

HSPF is a simulation model of the BASINS program developed by the USEPA. The model requires hourly meteorological data of the catchment area which was collected from AWS Hazratbal for the years 2012-2013. Other inputs including LULC map, point sources map, stream cover and sub basins layer of the catchment area were produced using the satellite image of the catchment area (LISS IV) provided by CCCMA-SKUAST-Kashmir and Arc GIS 10.2.

The simulated results for different water quality parameters were obtained and were calibrated using the meteorological data for the period April 2012-April 2013. Data was validated with the observed data for the period May 2013-May 2014. The results obtained were as follows:

- TSS were simulated to be in the range of 200-1000 mg/l. Simulated values of dissolved oxygen were found to be in the range of 9-13mg/l. Simulated values of water temperature were found between the range 2-29°C and that of turbidity were found to range from 0.4-80 ntu and 25-1000 ntu at site 2 and 3.
- Simulated values of TOC for layer 1 were found to lie between the range of 2.5-8 mg/l and for the lacustrine zone the values ranged between 2-9 mg/l. The simulated values of POC values were shown to range between 0.2-1.8 mg/l for layer 1 and 0-1 mg/l for the lacustrine zone. The simulated values of DOC values for layer 1 ranged between 2.2 and 5.8 mg/l and for the lacustrine zone the values ranged from 2.1-7 mg/l. The simulated values of TON values for layer 1 and lacustrine zone were found to range from 0.08-0.55 mg/l and 0.05-0.72 mg/l

respectively. The simulated values of TN values for layer 1 ranged from 0.08-0.55 mg/l and for the lacustrine zone the values were found to range between 0.04-0.75 mg/l.

- The simulated values of Ammonia ranged from 0.03-0.30 mg/l at layer 1 and 0.01-0.50 mg/l at lacustrine zone. Nitrate values were found to range 0.21-0.8mg/l at layer 1 and 0.28-0.93 mg/l at lacustrine zone. Total Phosphorous ranged between 0.02-0.28 mg/l for layer 1 and between 0.03-0.34 mg/l for lacustrine zone. Total Organic Phosphorous values ranged between 0.02-0.06 mg/l and 0.03-0.08 mg/l for layer 1 and lacustrine zone respectively. Total Phosphate values for layer 1 ranged from 0.02-0.23 mg/l and 0.04-0.29 mg/l for lacustrine zone.
- The comparison of land use classes for the year 1991 and 2013 shows a decrease of 1.15% in agricultural field, 2.28% in barren land, 5.35% in evergreen forests, 6.5% in orchards and horticulture, 0.41% in open forests, 0.15% in grasslands and meadows and 0.72% in waterbody. An increase of 7.91% in built up, 2.4% in mixed plantation, 0.62% in recreational park, 1.86% in scrub land and 3.17% in vegetable field was ascertained.

CONCLUSIONS

Based on these results and the comparison of the LULC of the year 1991 and 2013 the following management strategies in the catchment area were suggested as under:

- The simulated values of the water quality parameters were found to be on the threshold of being unsuitable for irrigation as well as aquatic life. The estimated values for the different water quality parameters suggested that the water is suitable for irrigation, domestic use and aquatic life but is not feasible for drinking purposes.
- The simulated water quality values and the land use changes detected in the catchment area in the last 23 years suggested that
 - An effective watershed prioritization should be worked out.

- Land use in the catchment should be regulated so to prove the best for the lake.
- The use of organic fertilizers should be encouraged.
- Unplanned urbanization should be checked by the authorities.
- An effective and comprehensive rehabilitation and management system should be evolved by irrigation engineers and planners for regular monitoring of Lake.
- More sewage treatment plants should be established on the areas so that the sewage water from the residential houses/hotels and interior areas of the lake are not directly discharged into the water bodies in order to prevent the further deterioration of the lake.
- Desilting and dewatering of the lake should be carried out on regular basis.
- Water quality monitoring should be done more frequently.
- Temporal and other geomorphological changes that take place in the lake environ should be monitored by using high resolution satellite data and ground based information and use of satellite based maps as a basic parameter for monitoring of the lake environs should be fortified.

Scope for Future Study

Despite some problems with the availability of data this research has demonstrated the usefulness of remote sensing, GIS and simulation of modeling for determining the water quality in the lake catchment. Due to the non-availability of best management practices data and the limited hourly meteorological data which are used as inputs to the HSPF model the results could be generated for only a year. The research can be taken forward by incorporating these data inputs required by the model to calculate the water quality having higher degree of precision and accuracy.

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Annexure -1

Month	Surface		Bottom	
	Observed	Simulated	Observed	Simulated
April	0.1	0.11	0.08	0.1
May	0.15	0.18	0.1	0.16
June	0.11	0.2	0.15	0.28
July	0.1	0.18	0.46	0.42
August	0.09	0.22	0.52	0.48
September	0.15	0.28	0.47	0.28
October	0.1	0.16	0.14	0.16
November	0.1	0.12	0.14	0.14
December	0.11	0.1	0.11	0.12

a) **Observed and simulated values of ammonia at surface and bottom layers of the lake.**

site1		site2		site3	
Simulated	Observed	Simulated	Observed	Simulated	Observed
9	9.8	8.8	9.2	8.8	8.5
8.4	9.5	8	9	9.2	8
7.8	7.3	7.6	7.3	7.5	7.8
7.5	8	7.4	9.02	7.8	7.5
7.6	8	6.6	6.2	7.6	7.2
8.8	9.8	6.8	8.2	9.4	8.8
7.2	8.8	7.5	6.8	9	9.2
9.1	8.5	8.8	9.8	10	9.5
10.5	10.2	10.5	10	11.8	10
11.4	11	11	10.6	10.8	11.6
11.2	10.8	10.6	12	11	10.4

b) **Observed and simulated values of dissolved oxygen at surface and bottom layers at different sites of the lake.**

Month	Surface		Bottom	
	Observed	Simulated	Observed	Simulated
April	0.68	0.77	0.69	0.72
May	0.66	0.77	0.75	0.87
June	0.3	0.43	0.42	0.63
July	0.3	0.25	0.31	0.38
August	0.34	0.29	0.34	0.41
September	0.34	0.49	0.48	0.52
October	0.68	0.56	0.59	0.47

c) Observed and simulated values of Nitrate at surface and bottom layers of dal lake

Month	Observed	Simulated
April	0.52	0.45
May	0.49	0.48
June	0.44	0.48
July	0.67	0.55
August	0.68	0.65
September	0.82	0.58
October	0.63	0.67
November	0.55	0.58
December	0.48	0.42

d) Observed and simulated values of total organic nitrogen in Dal Lake.

Month	Obsc	Simulated
April	(0.025
May	0.02	0.038
June	0.025	0.045
July	0.034	0.15
August	0.12	0.17
September	0.18	0.23
October	0.22	0.24

e) Observed and simulated values of phosphorous in Dal Lake.

Month	Observed	Simulated
April	0.02	0.02
May	0.03	0.03
June	0.03	0.04
July	0.02	0.05
August	0.01	0.04
September	0.04	0.03
October	0.03	0.04

f) Observed and simulated values of total organic phosphorous in Dal Lake.

Month	Observed	Simulated
April	0.05	0.04
May	0.04	0.06
June	0.06	0.08
July	0.1	0.13
August	0.16	0.2
September	0.17	0.27
October	0.23	0.25
November	0.22	0.23
December	0.21	0.21
January	0.18	0.2
February	0.17	0.19
March	0.18	0.18
April	0.17	0.17

g) Observed and simulated values of total organic phosphorous in Dal Lake.

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CERTIFICATE

Certified that all the corrections/amendments as suggested by External Examiner Dr. Manzoor Ahmad Ahanger, Dean Academic affairs , Department of civil Engineering, NIT, Srinagar during thesis Viva-Voce examination held on 26th of April have been incorporated in the final manuscript entitled, “**Integration of GIS with Hydrologic Model to Determine Water Quality of Dal Lake**” submitted by **Er. Anaum Chishti** (Regd. No. 2014-AE-20-M) of Soil and Water Engineering discipline.

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