

## EXECUTIVE SUMMARY

As a part of an over-all phosphorus analysis and management program within the Rock River Basin, a comprehensive pollution source computer modeling effort was conducted. This chapter summarizes the background, goals, methodology, and results of that modeling task.

### Background

Through the promulgation of Administrative Code NR 217 in 1992, wastewater treatment facilities in Wisconsin were required to achieve an effluent standard for phosphorus of 1.0 mg/l for chemical treatment and 1.5 mg/l for biological treatment. The administrative code allows for alternative limits if it can be demonstrated that achievement of the 1 mg/l limit will not “result in an environmentally significant improvement in water quality and material progress towards the attainment and maintenance of associated water quality standards for the receiving water body...” (NR 217.04(2)(b)1.

As a result of NR 217, a group of municipal wastewater treatment facilities initiated the formation of a “partnership” – The Rock River Partnership (RRP) to assess water quality management issues within the Rock River Basin in an integrated watershed-based approach. The RRP is made up of a variety of interest groups and stakeholders within the Rock River Basin. Representative members include state agencies, municipal wastewater operators, industries, private citizens, and environmental organizations. Members of the partnership signed a Memorandum of Understanding (MOU) in 1997 to define the goals and responsibilities of the RRP.

Five tasks were broken out to assess phosphorus in the Rock River Basin:

1. Monitor water quality and flow at selected locations within the basin to calculate mass loadings and analyze selected pollutant concentration
2. Through the use of a computer simulation model(s) calculate the sources and quantity of phosphorus loading to the surface water of the Rock River Basin
3. Develop and analyze issues related to pollutant trading approaches such as: nonpoint-to-point pollutant trade ratios, allowable geographic locations of trades in relation to point source dischargers, administration of a trade, etc.
4. Develop nonpoint source and point source phosphorus control cost summaries for various management approaches
5. Analyze the relationship between ambient phosphorus concentrations and observable in-stream impacts to the aquatic vegetation, habitat, aesthetics, and trophic conditions.

The remainder of this summary details Task #2.

### Goals and Model Selection

The focus of the modeling was to construct an intermediate level macro-scale model to better quantify phosphorus loading from point and non-point sources throughout the basin. The three major goals of the modeling effort were:

1. Estimate the average annual phosphorus load from external sources to the Rock River system.
2. Estimate the relative contribution of phosphorus loadings from nonpoint and point sources.
3. Estimate changes in average annual phosphorus loads from the application of global nonpoint source best management practices and point source controls (based on NR 217 effluent levels).

Several models were evaluated based on the size of the Rock River Basin, data requirements, and project objectives. Models evaluated included SWAT, HSPF, WINHUSTLE, AgNPS, XP-SWMM, and unit area loadings. The selection of SWAT was a decision agreed upon by the Rock River work planning subgroup, which included members from the RRP, WDNR, Earth Tech, and Strand Associates.

### **Description of the SWAT Modeling Effort**

SWAT (Soil and Water Assessment Tool) is the continuation of a long-term effort of nonpoint source pollution modeling by the USDA-Agricultural Research Service (USDA-ARS). The purpose of the model is to predict the effect of different management techniques on hydrology, sediment, and agricultural chemical yields in large unengaged watersheds. To satisfy these objectives, SWAT is a continuous time model (daily time step) which incorporates the effects of weather, surface runoff, evapotranspiration, crop growth, irrigation, groundwater flow, nutrient and pesticide loading, and water routing on the long-term impacts of varying management practices.

Even though the model was designed for use in unengaged watersheds, it was agreed that the model would be calibrated and validate to flow and phosphorous data (where available) from approximately 23 USGS gaging sites located throughout the basin. An average annual phosphorus load was then calculated for the basin using the calibrated model and compared (validated) to data collected in 1999 from the eight monitoring sites funded by the study. Once validated, the model was used to evaluate the effects of various management techniques (point and nonpoint sources) on phosphorus loading.

### Analysis of Phosphorus Management Scenarios

The modeling task included the evaluation of six different scenarios to assess the effect of global best management practices and the implementation of NR 217. These scenarios are described below:

1. Current agricultural practices with current point source discharges. This includes relative comparison by watershed of point and non-point sources.
2. Conventional tillage converted to conservation tillage and existing conservation tillage converted to no-till with current point source discharge levels.
3. Current tillage practices with nutrient management practices employed and current point source discharge levels.
4. Conventional tillage converted to conservation tillage and existing conservation tillage converted to no-till and nutrient management practices with current point source discharge levels.
5. Current agricultural practices with point source discharge phosphorus concentrations reduced to 1mg/l (the level designated in NR217).
6. Conventional tillage converted to conservation tillage and existing conservation tillage converted to no-till and nutrient management practices employed with point source discharge levels at 1 mg/l.

Table ES-1 summarizes the management scenarios described above.

**Table ES-1: Phosphorus Loading Management Approaches Analyzed by SWAT**

Management Scenario	Nonpoint Source (cropland) Management		Point Source Management
	Tillage Practices	Nutrient Management	Effluent Concentrations
1	Current	Current	Current
2	Improved	Current	Current
3	Current	Improved	Current
4	Improved	Improved	Current
5	Current	Current	NR 217 levels
6	Improved	Improved	NR 217 levels

Each of these scenarios was run for the period 1989-1996. This period provided a good evaluation because of the distribution of high flow, low flow, and normal flow years.

#### Limitation of the SWAT Model

Due to budget and time constraints, an exhaustive study could not be performed. Detailed in-stream water quality modeling involving fate and transport was not simulated. Once in the aquatic system, sediment and nutrients were modeled conservatively with minimal interactions using default QUAL2E routines. Data was collected from available sources and agricultural practices were limited to standardized practices. To minimize the potential for inappropriate use of output data from the modeling effort, it is important to keep in mind the limitations of the model. These limitations are identified below:

1. The model will not target specific sites (for example: cropped fields) for effluent trades.
2. The model will not “route” phosphorus beyond the sub-watershed level and will not predict the effects of in stream phosphorus loads on overall water quality.
3. There is a significant degree of uncertainty associated with the output from nonpoint source models, however, this modeling effort will provide a general indication of the annual phosphorus load for a sub-watershed for a given set of conditions.
4. An exhaustive evaluation of nonpoint control options was not made. The control options were limited to 1) modifications of fertilizer application rates; and 2) changes in tillage practices. Additional phosphorus reductions could be gained through the application of other BMPs such as buffer strips, various urban control practices, artificial wetlands, and other applicable practices.

#### **Procedure for Developing the Rock River SWAT Model**

To ensure that modeling results would meet the needs of this study and to test specific routines in the SWAT model, two pilot areas were selected for testing the model and verifying its capability to accurately predict water, sediment and phosphorus loads. The criteria for selecting the areas included size (less than 90 square miles), completeness and availability of USGS gaging and monitoring data, and minimal influences from dams, lakes, urban areas, and point sources on the hydrology and water quality within the pilot areas. The gaging stations that best met these criteria were the Yahara River at Windsor and Jackson Creek at Petrie Rd. Once SWAT was successfully applied to these pilot areas, full-scale modeling commenced

The categories of data necessary for modeling is summarized below:

Climate/Hydrologic Data

Stream gaging  
Hydrologic data  
Precipitation  
Temperature  
Dams, lakes, & wetlands data

Land Data

Land cover  
Topography  
Soils characteristics  
Cropland management practices  
Point source phosphorus and flow data

Information was obtained from public agencies including the U.S. Geologic Survey (USGS), Wisconsin Department of Natural Resources (WDNR), U.S. Department of Agriculture, Wisconsin Department of Agriculture Trade, and Consumer Protection (WDATCP), and County Land Conservation Offices. USGS historical flow records were obtained for twenty-three locations throughout the Rock River Basin. Land use information was determined from the WISCLAND coverage created through satellite imagery. Individual County Land Conservation Agents verified agricultural land use and general practices. Tillage practices were determined using a transect survey performed by the USDA in 1998. The STATSGO soil data coverage for the state of Wisconsin was used for soil inputs and the USGS 30-meter digital elevation model (DEM) was used to generate contours, derive average slopes, and delineate watershed boundaries. Climate data for 18 monitoring stations was obtained from the State Climatologist Office. Point source data was collected from WDNR permit records where available. Additional information was obtained from a survey sent to all municipal and industrial point sources within the Rock River watershed. An effluent discharge concentration of 4 mg/L was assumed for phosphorus if no response was received from the permitted source.

Internally Drained Areas: During delineation and calibration of the two pilot areas (Jackson Creek at Petrie Road and Yahara River at Windsor), Earth Tech noted discrepancies between the drainage area reported by the USGS and the actual contributing area (surface water flow). The total water yield reported by the USGS is based on the total drainage area, which often includes internally drained areas. In the model, failure to properly account for these internally drained areas produces excess runoff and reduces groundwater base flow. To identify internally drained areas, Earth Tech manually verified the delineation of the pilot areas produced by AVSWAT against digital USGS quad maps and then modified the computer generated drainage boundaries as needed.

Lakes, Impoundments and Wetlands: The Rock River basin includes many lakes, wetlands, and impoundment areas that affect the flow of water. Wetlands were modeled within SWAT based on the area of the wetlands, the volume of water necessary to fill the wetlands, contributing drainage area to the wetlands, and infiltration rate. The wetland's area was obtained from the WISCLAND coverage and infiltration rates were based on rates for hydric soils located throughout the basin. The pond subroutine was used to model small lakes and ponds. Input requirements are similar to those of the wetland routine, however, ponds were modeled using a lower infiltration rate than the wetlands. The reservoir routine was used to simulate large impoundments. Only reservoirs that significantly impact the flow of water through the watershed were included in the model. Significant reservoirs were selected based on reservoir storage, surface area, and the amount of contributing drainage area.

Point Source Phosphorus Loads: Monthly phosphorus loads from point source discharges were calculated several ways. Where less than one year of data was available, the average concentration was calculated from available data and loads were calculated using the average monthly flow. Where no phosphorus data was available, the monthly phosphorus loads were calculated based on an assumed average effluent phosphorus concentration of 4.0 mg/L and the calculated average monthly flows. If a full year of phosphorus concentration data was available, those values were used with the average monthly flows to

calculate an average monthly phosphorus load. If more than one year of data is available, average monthly phosphorus concentrations were calculated to determine the average monthly phosphorus loads.

Cropland Tillage Practices: A summary of tillage practices from a statewide transect survey by DATCP were used to help define agricultural management files. Percent and actual acreage of tillage practices was summarized by watershed. This data was used to generate and vary the tillage practices among watersheds. Interviews with county agents, UW-Extension, and examination of the WISCLAND coverage were used to determine and verify cropping practices.

Crop Yields: SWAT reports annual crop yields for the simulations. Variables used to adjust crop yields for corn, soybeans, and alfalfa were adjusted so crop growth would better reflect conditions in southern Wisconsin. Crop yields were used to verify that the crop is growing properly within the model. Crop yields affect model variables including soil moisture, evapotranspiration, and available bio-mass. Predicted crop yields were compared to actual measured yields published in USDA agricultural statistics. It should also be noted that SWAT does not have an input for percent residue, rather the tillage practice is modeled as percent incorporation. The actual percent residue varies over time and SWAT models the breakdown of residue into organic matter or humus.

Urban Runoff: SWAT utilizes USGS regression equations to simulate the build-up and wash-off of pollutants from urban areas. Construction erosion has been identified as the largest source of sediment in urban areas. An attempt was made to estimate the amount of construction erosion occurring in each watershed however; insufficient information is readily available to generate such estimates. Because a relationship between population growth and acreage of construction could not be established, the sediment load due to construction sites was not - broken out from the nonpoint load.

### Model Calibration

Calibration was performed in three sequential steps: (1) first hydrology was calibrated, (2) in-stream sediment loads were calibrated, and (3) phosphorus loads were calibrated. Simulated results were compared to USGS gaging data. Hydrology was calibrated by comparing both total average annual water yields and daily flows. Once average annual water yields were within acceptable ranges, daily flows were adjusted to match monitored results during both high and low flow periods. In-stream sediment loads were calibrated by adjusting the peak or event load and the baseflow load. The baseflow concentration was estimated using values from "Measurement and Prediction of Sediment Yields in Wisconsin Streams" by the USGS. Phosphorus loads were broken down into soluble and sediment contributions. In general, the phosphorus loads predicted by SWAT were higher than those monitored at gaging stations. This can be attributed to fate and transport phenomena, which was not simulated in this modeling effort.

It is important to note that several discrepancies in data obtained from USGS gaging stations have been noticed and influenced calibration. Particular periods of concern are during the spring when ice jams may cause gauges to record artificially high flow measurements. The USGS generally "flags" this data as being suspect, however there may be occurrences where these discrepancy were missed. In cases where spring flows appear to be influenced by ice jams, calibration for this period was not conducted.

To analyze the accuracy of the SWAT results to measured values, the Nash-Sutcliffe coefficient of efficiency, and R-squared values were utilized. It was agreed to by the WDNR, the RRP and Earth Tech that based on other modeling exercises, that values greater than 0.6 from either test applied to the annual flow values would be considered an acceptable fit. R-squared values tend to be higher than Nash-Sutcliffe values because an outlying value on a single event will significantly lower the Nash-Sutcliffe coefficient while only slightly affecting the R-squared value. Calibration results are shown later in this chapter.

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### Corrections and Modifications to the SWAT Model

During the modeling of the pilot areas, several errors were found in the SWAT code and manual, which required correction. In addition, several routines were modified to better reflect conditions in the Midwest. All modifications were reviewed and approved by the developers of the SWAT model.

During the modeling of BMP scenarios a significant error in the in the phosphorus routine was found. It was discovered that SWAT did not report phosphorus attached to sediment particles and did not properly route soluble phosphorus. This is of significance because phosphorus transported by sediment typically makes up the greatest portion of nonpoint phosphorus loads. The developers of SWAT at Texas A&M and Paul Baumgart of Fox-Wolf 2000 corrected this error.

## Results of the SWAT Modeling Task

### Calibration

The modeling generated considerable data. The full report on the SWAT modeling project contains a more comprehensive reporting of results including validation data. Below is a summary of the calibration results for the periods and stations listed. In general, the calibration procedure compared favorably to monitored data. Validation data supported that the model was accurately predicting flows, sediment, and phosphorus on an average annual basis.

**Table ES-2: Summary of Average Annual Flow (inches of runoff) Calibration**

USGS Station		Period	Avg. Annual Inches of Runoff			COE	R <sup>2</sup>
			SWAT Model	USGS Monitored	% Difference		
5423500	Upper Rock R.	1989 – 1996	4.66	9.30	50%	-0.316	0.696
5425500	Upper Rock R.	1989 – 1996	7.79	8.84	12%	0.425	0.775
5425912	Crawfish R. (Beaver Dam R.)	1989 – 1996	14.82	9.30	59%	0.443	0.726
5426000	Crawfish R.	1989 – 1996	9.12	9.24	1%	0.370	0.646
5426031	Middle Rock R.	1989 – 1996	9.33	8.53	9%	0.570	0.977
5426250	Bark River	1989 – 1996	9.34	9.26	1%	0.683	0.684
5427948	Yahara R. (at Pheasant Br. Cr.)	1989 – 1996	3.99	3.72	7%	0.671	0.686
5430500	Rock R. at Afton	1989 – 1996	8.86	8.83	0%	0.758	0.777
5431486	Turtle Creek	1989 – 1996	8.53	8.18	4%	0.549	0.720
5430150	Yahara R. (at Badfish Cr.)	1994 – 1998	14.83	18.61	20%	-0.080	0.026
5430175	Yahara R.	1994 – 1998	8.51	10.76	21%	0.049	0.064
5431022	Turtle Creek	1989 – 1996	7.51	6.29	19%	0.184	0.459

### Basin-wide Phosphorus Loading

Under existing land use and management conditions (scenario 1), the model predicted a total basin average annual phosphorus load of approximately 1,680,000 pounds. Point sources accounted for 41% of this value, and 59% was from nonpoint sources. These numbers are reported as total phosphorus and do not distinguish between the different forms (ortho, soluble, particulate, etc.) of phosphorus.

It is important to note that the cropland BMP practices that were analyzed were limited to two options: modifications in tillage practices, and adoption of recommended nutrient application rates. No other BMP practices (i.e. urban controls and riparian buffer strips, etc.) were simulated. Thus, *the loads depicted by SWAT under these management scenarios do not necessarily represent the lowest attainable loads*. Estimates in load reduction from the application of other nonpoint BMPs is summarized in “A review of Agricultural and Urban Best Management Practices for the Reduction of Phosphorus Pollution”, (Chad Cook, May 1999). This document is available through the WDNR (PUBL-SS-943-99). The results listed in this document should be used as a guide only as many of the BMPs discussed are influenced by site-specific criteria.

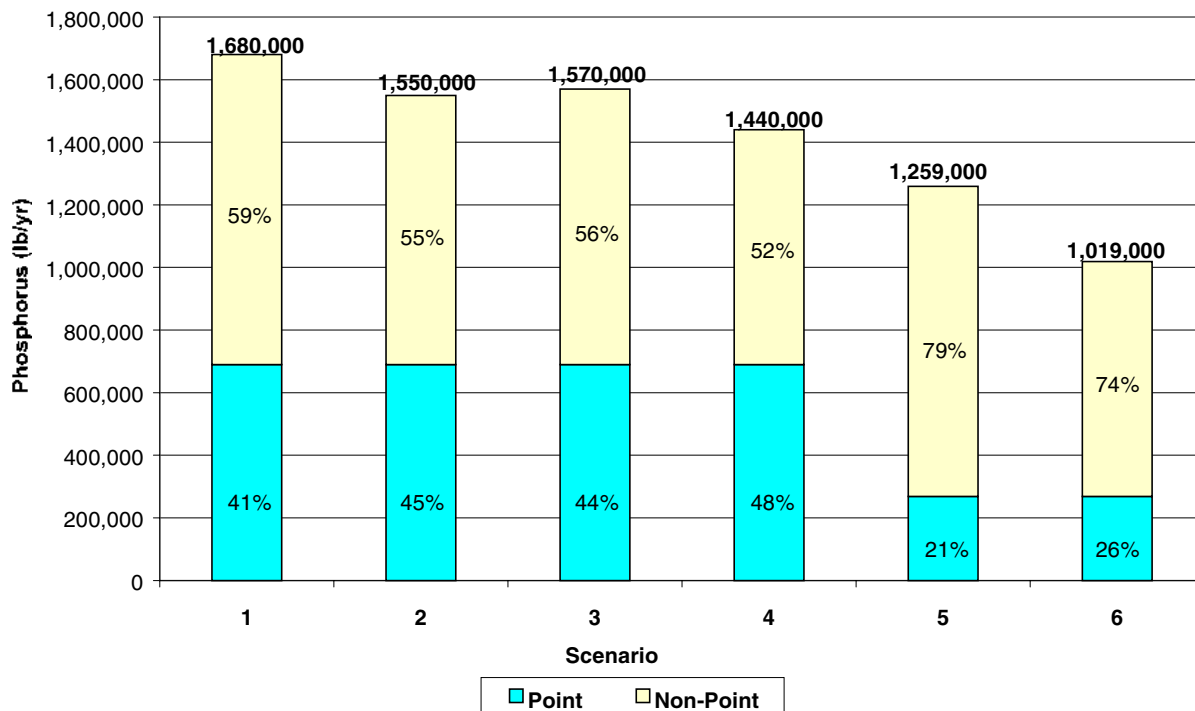
The implementation of alternative tillage practices was limited to conventional tillage being changed to conservation tillage and existing conservation tillage being phased into no-till. In the opinion of UW-

Extension staff and county LCD staff, changing from conventional tillage to no-till systems was not likely to immediately occur.

Implementation of improved nutrient management was limited to fertilizer applications. Since no infrastructure currently exists for “manure trading”, manure application rates remained unchanged. Fertilizer application rates were reduced from the existing average application rates to the recommended application rates. Actual application rates should be based on soil test values, however, since this data was too specific for the scope of the project, application rates were set a UW-Extension “generic” recommended rates.

Figure ES-1 is a bar chart depicting point and nonpoint loads for each of the six management scenarios modeled. The scenarios shown correspond to those described above. Evaluation of various BMP scenarios shows that with implementation of NR 217 (applicable point sources effluent at 1 mg/l of phosphorus) and changes in tillage practices and nutrient application practices, the total phosphorus can be reduced across the basin by approximately 40% (Scenario 1 to 6). An estimated 25% reduction in phosphorus loads can be obtained by implementing NR 217 (Scenario 1 to 5) and a 14% reduction can be obtained with implementing improved tillage and nutrient management practices (Scenario 1 to 4).

**Figure ES-1: Basin Phosphorus Loads by Scenario**



These scenarios are not an exhaustive evaluation of potential BMPs. They do not include implementation of urban BMP practices, wetland restoration, or the construction of buffer strips. They do however provide a general indication of the level of control that can be achieved.

In addition to phosphorus loads, information was generated on sediment loads stemming from nonpoint sources. Modeling results indicate that under existing conditions, approximately 160,000 tons of sediment is delivered to the waterbodies within the Rock River Basin on an average annual basis. Bed-load re-suspension, and scour can account for discrepancies with monitored loads at in-stream gages. SWAT predicted that through the implementation of improved tillage practices (predominantly conservation tillage), sediment yields could be reduced by almost 20%.

## Conclusions

1. Under current conditions, nonpoint sources of phosphorus contribute 59% of the total loading to the Rock River Basin's water resources. The remaining 41% comes from point sources. *NOTE: The analysis did not account for other phosphorus sources such as atmospheric deposition, groundwater, etc.*
2. With global application of improved tillage and nutrient management practices, the basin-wide annual phosphorus loads from cropland runoff can be reduced by 224,000 pounds (14% reduction from the total). *NOTE: This reduction only accounts for two agricultural management measures. Other management practices, (such as riparian buffers, manure management, streambank stabilization, barnyard runoff controls, urban stormwater management, and pasture management) were not analyzed. Thus the potential total phosphorus reduction from all nonpoint source pollution is greater.*
3. With the complete application of the NR 217 phosphorus effluent standards, the basin-wide annual phosphorus loads from permitted discharges can be reduced by 421,000 pounds (25% reduction from the existing total).
4. The phosphorus loads, the level of potential phosphorus control, and the significance of the sources (point and nonpoint) varies greatly from watershed to watershed throughout the basin. In some cases, point source controls alone produce a significant drop in phosphorus loads while in other watersheds nonpoint source controls or a combination of both point and nonpoint controls is required to reduce loads.

## Recommendations

This study concentrated on phosphorus and sediment loads delivered to receiving surface water bodies and did not attempt to relate these loads to the impact on water quality conditions. This was not due to an inability of the model to simulate receiving water quality rather the project's scope of work did not include these analyses.

Possible further modeling studies should be considered. Possible future work should be weighted against the expected improvements in technical understanding. It is important to balance our level of understanding and to work in areas where reducing the existing level of uncertainty will have the biggest effect on management decisions. It is important to agree on the scope, cost and data needs of such projects. Additional modeling and research should not overshadow the need for action. In some cases, models just provide a quantitative answer to a question that has already been answered in a qualitative manner. Thus additional modeling should not be performed in place of or delay the implementation of BMPs with known benefits. Based on the results of the modeling, a summary of recommended actions is listed below. The recommendations listed below are not ranked in any particular order.

- In-stream water quality modeling through either stochastic or quantitative techniques to relate the loads generated in this study to in-stream conditions. This effort should examine the fate of both

point and nonpoint sources of phosphorus and the impact of phosphorus (in regards to trophic conditions) on the water resources in the Rock River Basin. The results of this effort could be used to help determine numerical water quality criteria as it relates to the type of water body and its intended use. In other words, the load allocation (LA) and waste load allocation (WLA) portions of a total maximum daily load (TMDL) could be calculated.

- Continuation of sampling at key locations to provide additional data for development of both numerical and stochastic models. Monitoring records are also needed to generate trends and assess the effectiveness of BMPs.
- SWAT presented a reasonable estimation of loads at the sub-watershed scale, however, a more refined analysis may be warranted to target specific nonpoint BMPs. Past and current research shows that individual fields can contribute significant phosphorus loads to surface waters through runoff and sediment loss. Efforts need to be concentrated on identifying these fields and enacting necessary controls.
- Determine nonpoint phosphorus loads that will occur even with the implementation of all potential BMPs. This scenario represents a best case and will require the inclusion of additional BMPs not addressed in this study. Even under this best case scenario, nonpoint phosphorus loads are not zero. The best case point and nonpoint loads should be compared to water quality standards to evaluate the attainability of instream standards.

It is important that guidelines, BMPs, and restrictions on phosphorus usage have a scientific basis. The models and tools for evaluating water quality and pollutant loads are continually evolving. Improvements in modeling should be matched with improvements in both point source controls and nonpoint BMPs. Given the complexity and magnitude of the problem, there is no single solution; rather various practices will need to be employed.