Journal of Environmental Science and Engineering B 15 (2026) 145-158
doi:10.17265/2162-5263/2026.04.001

Field Sampling and Chemical Analysis of Atrazine-Contaminated Water/Sediment in the Rio Grande Basin Region

Venkata M. Palla[1], R. Sadu[1], R. Asapu[1], G. Spencer[1], D. Chen[1], K. Urbanczy[2] and G. Falzarano[2]

1. Lamar University, Beaumont, Texas 77710, USA

2. Sulrsoss State University, Alpine, Texas 77710, USA

Abstract: Water and sediment samples collected from the Rio Grande Drainage Basin were analyzed for atrazine, an herbicide, and hydroxyatrazine, its primary degradation product, using High Performance Liquid Chromotography (HPLC). The geographical and seasonal distributions of the atrazine contamination were determined and the sites where the collected water/sediment samples were above Environment Protection Agency (EPA) level of concern (Atrazine + Hydroxyatrazine > 37.5 ppb) were identified. The atrazine entrained in the sediment was extracted by the Soxhlet hot solvent extraction with dichloromethane/acetone 65:35 v/v solvent followed by the HPLC analysis. The amount of atrazine was also calculated using the soil sorption coefficient correlation. Atrazine entrained in sediment sometime exceeded the EPA levels of concern and can pose a long-lasting threat to the water quality in the Rio Grande region.

Key words: Atrazine, hydroxyatrazine, chromotography.

1. Introduction

Contaminants from industrial and agricultural wastes pose a major environmental threat to air and water. Atrazine ($C_8H_{14}ClN_5$) is the most extensively used herbicide to control weeds in agricultural crops, and is widely found in agricultural water [1]. During the past two decades in the United States alone, annually 30 to 40 million kilograms of atrazine are applied to approximately 70 million acres of corn, sugarcane, and other crops [1]. Much makes its way into streams, rivers, lakes and drinking water supplies. Atrazine may cause cardiovascular damage, muscle and adrenal degeneration, and congestion of heart, lungs, and kidneys in humans [2]. Moreover, it is toxic to aquatic organisms and may cause widespread harm to endangered species. Studies show that atrazine causes deformities in frogs including hermaphroditism [3]. Through its authority under Section 304(a) of the Clean Water Act, US EPA 2003 has developed ambient water quality criteria for atrazine for the protection of aquatic life and drinking water [1]. US EPA's screening-level assessment conducted for the atrazine one-day concentrations showing less than the DWLOC (Drinking Water Level of Concern) of 298 ppb does not pose a risk to human health for short term exposure [4-6]. US EPA level of concern for drinking water is an intermediate level of exposure if, in a 90-day rolling average, the concentration exceeds 37.5 ppb for atrazine and its degradates in raw water [4, 6]. The atrazine MCL (Maximum Contaminant Level) is intended to prevent longer-term, or chronic, health concerns from occurring even after years of exposure and is calculated against a running average from four quarterly samples; the consistent value above a yearly average of 3 ppb would be of concern [4-7]. However, the maximum concentrations of atrazine have been

Corresponding author: Venkata Manohar Palla, Ph.D., Chemical Engineering, research fields: environmental engineering and chemical analysis.

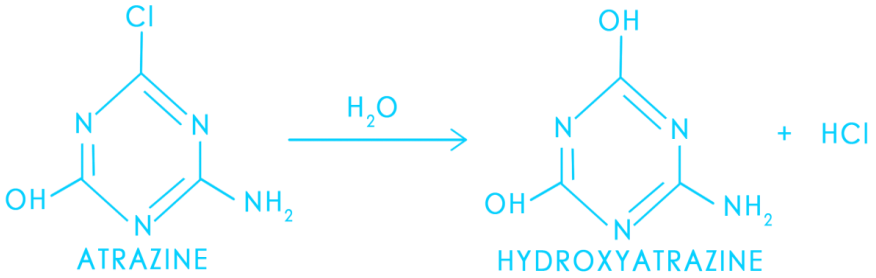

Fig. 1 Phytolysis of atrazine to hydroxyatrazine.

reported to be up to 70 μg/L in Midwestern agricultural areas in the United States [1]. Under usual water conditions, the half life of atrazine is 742 days [8]; thus, typically it is removed from municipal water supplies by means of expensive powdered/granulated activated carbon filtration units. However, most public water supply systems in the state of Texas do not have these units to remove atrazine from the water supply [9]. In 1997 and 1998 high levels of atrazine were detected in Aquilla Lake near Hillsboro, TX, which triggered projects to address agricultural sources of the herbicide by the predecessor of Texas Commission on Environmental Quality [10]. The major by-product formed during the phytolysis of atrazine is hydroxyatrazine ($C_8H_{15}N_5O$); the reaction is shown in the Fig. 1 [11].

Atrazine pollution also occurs in the soil. The atrazine and its metabolites can persist for months in some soils and seasonal carry-over can cause phytotoxicity problems in crop rotation [12]. Detection in soil is necessary for the environmental fate studies. For the detection of the water contamination requires the determination of these analytes in soil. In the soil surface, the processes of retention and degradation of herbicides are closely related to the proportion of TOC (Total Organic Carbon) content and the microbial activity [12, 13]. There are different methods in the determination of atrazine in soil samples like sonication, shaking, SFE (supercritical fluid extraction) and hot solvent Soxhlet extraction. SFE has been found more efficient than sonication and shaking but the results are not consistent. Hot Solvent Soxhlet extraction method has high atrazine recovery of about 98% when it is extracted with dichloromethane/acetone 65:35 v/v as solvent [14]. The analysis of the atrazine in this work was done by HPLC (High Performance Liquid Chromatography).

2. Field Expeditions

Fourteen expeditions were conducted during the years of 2006-2011 for three different seasons (Spring, Summer and Fall) to collect field samples of both water and sediment from the Rio Grande Drainage Basin. The chemical analysis for water (and water in equilibrium with sediment) was carried out using an Agilent 1100 HPLC with a variable wavelength detector at 222 nm (detection limit is 0.5 μg/L) for both atrazine and the main photolysis by-product hydroxyatrazine. The sediment samples were extracted with dichloromethane/ acetone 65:35 v/v as a solvent using the Hot Solvent Soxhlet Extraction method to extract the atrazine adsorbed in the sediment [14]. The results were compared with the soil adsorption coefficient (K_{oc}) correlation [15, 16]. Table 1 shows the locations of the field sampling collected in Rio Grande region for the chemical analysis of atrazine & hydroxyatrazine.

3. Materials and Reagents

Atrazine (Sigma Aldrich), hydroxyatrazine (Sigma Aldrich), acetonitrile (Sigma Aldrich, HPLC gradient grade), dichloromethane (Sigma Aldrich), acetone (Sigma Aldrich), KOH (Sigma Aldrich), and potassium dihydrogen phosphate (Sigma Aldrich) were used without further treatment. Mobile phase for the HPLC consisted of acetonitrile and distilled water. All the chemicals were of analytical grade and used without any further treatment.

Table 1 Sample locations for the field samples.

Site No.	Location	Abr. city	City	County	State
1U	International bridge	FtHk	Fort Hancock	Hudspeth	Texas
2U	Bridge	SnPk	Sunland park	Dona Ana	New Mexico
3U	Bridge on 189	Vado	Vado	Dona Ana	New Mexico
4U	Dirt ditch behind dairy	Vado	Vado	Dona Ana	New Mexico
5U	Concrete drain behind dairy	Vado	Vado	Dona Ana	New Mexico
6U	Gauging station	Cand	Candelaria	Persidio	Texas
7U	Rio Grande	Ruids	Ruidosa	Persidio	Texas
8U	Gauging station	NPers	N.Persidio	Persidio	Texas
9U	Gaging station	SPers	S.Persidio	Persidio	Texas
10U	Lajitas	Ljts	Lajitas	Brewster	Texas
11U	Bibe	Cstln	Castolon	Brewster	Texas
12U	Bibe	RGVil	Rio Grande Village	Brewster	Texas
13U	Langtry	Lngty	Langtry	Val Verde	Texas
14U	Pecos river	NSmCn	N.Seminole Canyon	Val Verde	Texas
15U	Rock quarry	AmLk	Amistad lake	Val Verde	Texas
16U	Creek below cattle ranch	Edsn	Edison	Zavala	Texas
17U	Creek upper at cattle ranch	Edsn	Edison	Zavala	Texas
18U	International bridge	EgPs	Eagle Pass	Maverick	Texas
19U	Canon Grande Creek	EgPs	Eagle Pass	Maverick	Texas

4. Chemical Analysis

4.1 HPLC Analysis for Atrazine ($C_8H_{14}ClN_5$)

The field sampling was carried out in collaboration with the Sul Ross State University from various locations in the Rio Grande Drainage Basin to identify the extent and pollution sources of herbicides/pathogens. Water samples were collected two feet below the surface or at the mid-water column, and stored in 2 mL Amber vials. Sediment samples were stored in 20 mL Amber EPA vials. They were shipped in a cold box to the Lab in Lamar University overnight and analyzed at the earliest time.

Atrazine concentrations were analyzed with an Agilent 1100 HPLC system. HPLC was operated at room temperatures with an Eclipse XDB-C8 reverse phase column, a variable wavelength detector at 222 nm, and a mobile phase (40% water and 60% acetonitrile) flowrate at 0.2 mL/min. In all cases 20-μL samples were injected. The HPLC was calibrated with prepared standard atrazine solution. The detection limit was 0.5 μg/L. The HPLC system had a very good repeatability. The relative error was less than ±1% for atrazine detection. During analysis, water samples were injected to the column directly. Deionized water was first added to each sediment sample and well mixed to become a 30 wt.% suspension for atrazine extraction. The suspension was then centrifuged for 5 minutes and the top water is injected to HPLC column for atrazine detection. Atrazine peak from the HPLC analysis is shown in Fig. 2.

4.2 HPLC Analysis for Hydroxyatrazine ($C_5H_{18}N_5O$)

Hydroxyatrazine concentrations were analyzed with an Agilent 1100 HPLC system shown in Fig. 3. HPLC was operated at room temperatures with an Eclipse XDB-C8 reverse phase column, a variable wavelength detector at 222 nm, and a mobile phase (60% water and 40% acetonitrile) flowrate at 0.2 mL/min. In all cases 20-μL samples were injected. The HPLC was calibrated with prepared standard hydroxyatrazine solution. The detection limit was 0.5 μg/L. The HPLC

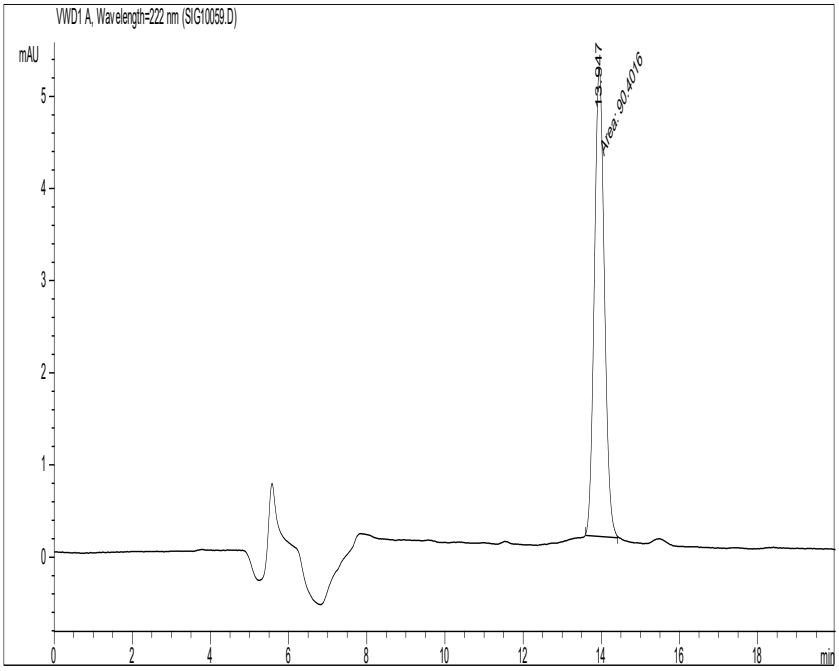

Fig. 2 Atrazine peak identified using HPLC.

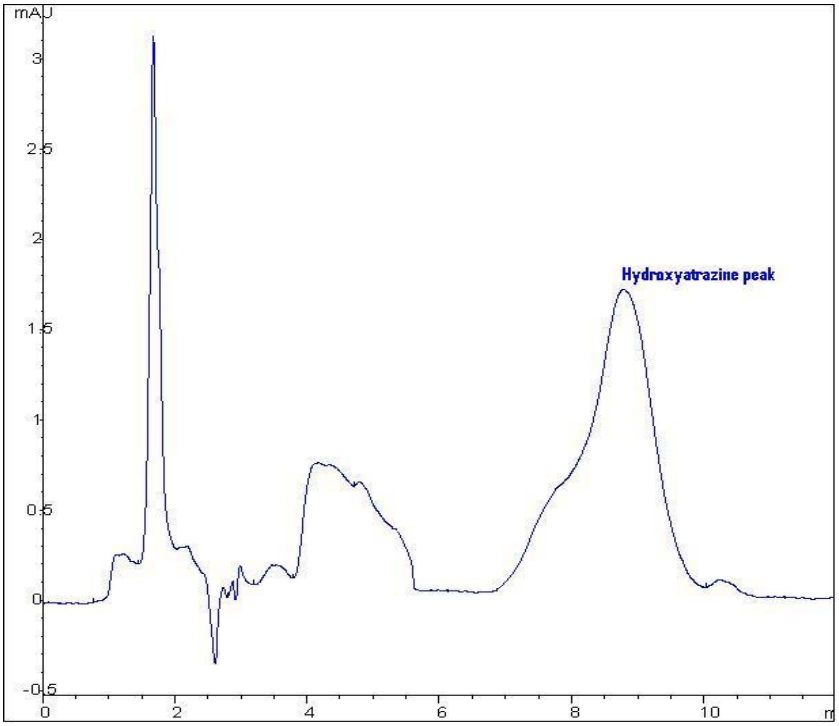

Fig. 3 Hydroxyatrazine peak identified using HPLC.

system had a very good repeatability. The relative error was less than ±1% for hydroxyatrazine detection. During analysis, water samples were injected to the column directly. Deionized water was first added to each sediment sample and well mixed to become a 30 wt.% suspension for hydroxyatrazine extraction. The suspension was then centrifuged for 5 minutes and the top water was injected to the HPLC column for atrazine detection. Hydroxyatrazine peak from the HPLC analysis is shown in Fig. 3.

5. Results and Discussion

5.1 Water Sample Analysis for Atrazine & Hydroxyatrazine

Field samples of water were collected during fourteen expeditions over the years 2006-2011 from the Rio Grande Drainage Basin. The chemical analysis for water was carried out using an Agilent 1100 HPLC with a variable wavelength detector at 222 nm (detection limit is 0.5 μg/L) of atrazine for the first ten expeditions from Sp. '06-Sum. '10. Atrazine and the main photolysis by-product hydroxyatrazine were analyzed for the last four expeditions from Fall 2010-Fall 2011. Atrazine and hydroxyatrazine peaks are shown in Figs. 2 & 3.

Atrazine was found in 5 (out of 38) in Sp. '06, 12 (out of 45) in Sum. '06, 5 (out of 38) in Fall '06, 1 (out of 36) in Sum. '07, 0 (out of 16) in Sp. '08, 3 (out of 26) in Sum. '09 (with the highest being 5.4 μg/L, Sunland park, NM), 8 (out of 17) in Fall '09 (with the highest being 11.6 μg/L, Lajtas, TX), 17 (out of 18) in Sp. '10 (with the highest being 35.3 μg/L, Vado, NM and 18 (out of 18) in Sum. '10 (with the highest being 27.2μg/L, Vado, NM).

Atrazine + hydroxyatrazine was found in 15 (out of 19) in Fall '10 (with highest being 46.6 μg/L, Langtry, TX), 1 (out of 18) in Sp. '11 (with highest being 25.2 μg/L, Langtry, TX) and 2 (out of 13) in Sum. '11 (with highest being 623.3 μg/L, Canon Grande Creek, TX) and 6 (out of 17) in Fall '11 (with highest being 86.5 μg/L, Castolon-Bibe, TX).

Fig. 4 displays the annual variation for the analyzed atrazine and hydroxyatrazine in water for the field samples collected from the Rio Grande Drainage Basin. The concentrations of atrazine + hydroxyatrazine appear to increase from 2006 to 2011.

Fig. 5 shows the seasonal variation for the water samples collected from the Rio Grande Drainage Basin with the summer season being the most likely to encounter high concentrations of atrazine + hydroxyatrazine.

Fig. 6 indicates the sites which exceed the EPA intermediate level of concern, i.e., 37.5 ppb of atrazine + hydroxyatrazine in water. The concentrations of atrazine + hydroxyatrazine exceed this level for 9 samples from 5 locations. The % of violation is the number of samples exceeding 37.5 ppb divided by the total number of samples collected from a particular site. The highest % of violation (40%, 2 out of 5 samples exceed 37.5 ppb of atrazine + hydroxyatrazine conc.) and the highest concentration (624 μg/L) in water samples were found in Canon Grande Creek, Eagle Pass, TX.

5.2 Sediment Sample Analysis of Atrazine & Hydroxyatrazine

Field samples of sediment were collected during fourteen expeditions over the years 2006-2011 from the Rio Grande Drainage Basin. The chemical analysis of water in equilibrium with sediment was carried out using an Agilent 1100 HPLC with a variable wavelength detector at 222 nm (detection limit is 0.5 μg/L) of atrazine for the first ten expeditions from Sp '06-Su '10. Atrazine and the main photolysis by-product hydroxyatrazine were analyzed for the last four expeditions from Fall '10-Fall '11. Atrazine and hydroxyatrazine peaks are shown in Figs. 2 & 3.

Sediment samples were collected from various expeditions. Atrazine was found in 5 (out of 23) in Sp. '07 (with the highest conc. of 46 μg/L, Texas), 2 (out of 15) in Fall 2007 (with highest concentration of 60.8 μg/L, Zaragosa Creek, Laredo), 0 (out of 16) in Sp. '08, 1 (out of 19) in Sum. '09 (with the highest conc. of 418 μg/L, Las Moras Creek, TX) , and 7 (out of 17) in Fall '09 (with the highest concentration being 38.4 μg/L, Amistad-Rock quarry, TX), 18 (out of 18) in Sp. '10 (with the highest being 216.6μg/L, Vado, NM) and 14 (out of 18) in Sum. '10 (with the highest being 121.2μg/L, Pecos River, TX).

Atrazine & hydroxyatrazine were found in 7 (out of 19) in Fall '10 (with the highest being 104.3 μg/L, Amistad Lake Rock Quarry, TX), 11 (out of 17) in

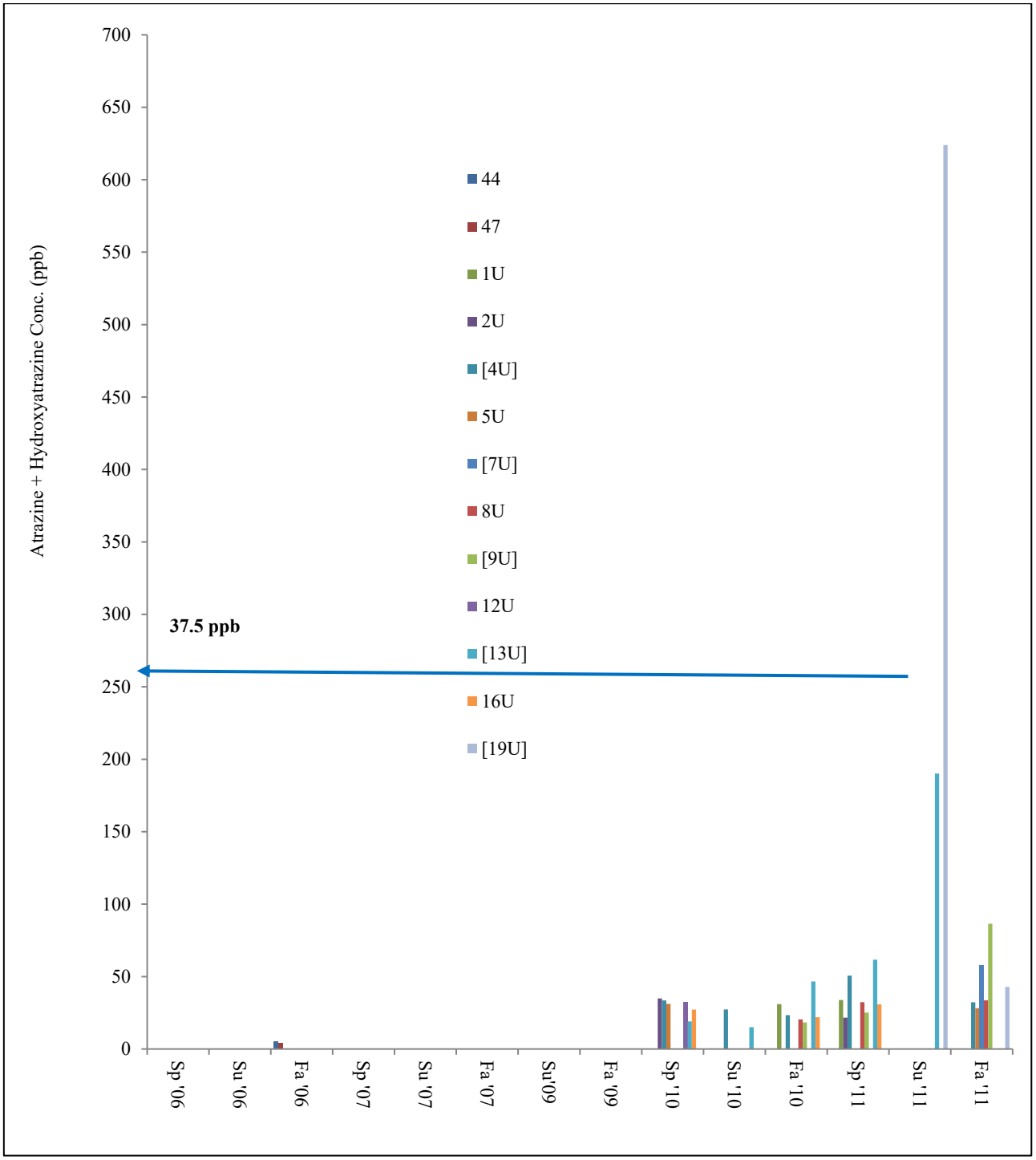

Fig. 4 Annual variations of atrazine + hydroxyatrazine analysis for the water samples collected from the Rio Grande region. [ ] indicates the sites which exceed the EPA level of concern (37.5 ppb of atrazine + hydroxyatrazine); during Sp '06-Sp '10 only atrazine was analyzed.

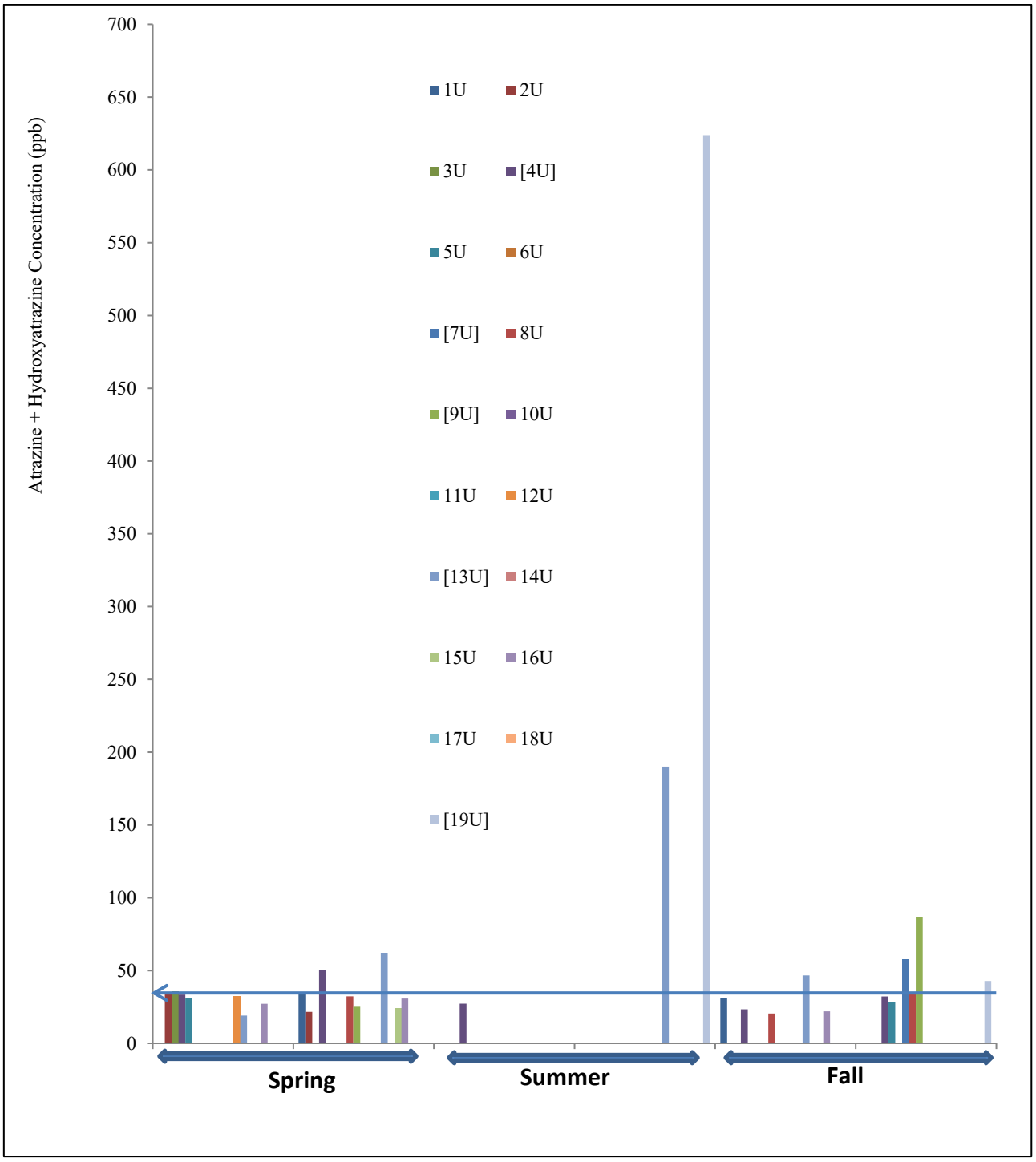

Fig. 5 Seasonal variation of atrazine + hydroxyatrazine analysis for the water samples collected from the Rio Grande region. [ ] indicates the sites which exceed the EPA level of concern (37.5 ppb of atrazine + hydroxyatrazine).

Fig. 6 Map Showing the site locations for water samples exceeding the EPA level of concern (37.5 ppb of atrazine + hydroxyatrazine).

Sp. ’11 (with the highest being 652.4 μg/L, Castolon-Bibe, TX), 3 (out of 12) in Sum. ’11 (with the highest being 256.2 μg/L, Gaging Station-N.Presidio, TX) and 4 (out of 16) in Fall ’11 (with the highest being 333.3 μg/L, Gaging Station-N.Presidio, TX).

Fig. 7 gives the annual variation for the analyzed atrazine and hydroxyatrazine in sediment for the field samples collected from the Rio Grande Drainage Basin. The concentrations of atrazine + hydroxyatrazine appear to increase from 2006 to 2011.

Fig. 8 shows the seasonal variation for the sediment samples collected from the Rio Grande Drainage Basin with the summer and spring seasons having the peak concentrations of the atrazine + hydroxyatrazine.

Fig. 9 displays the sites which exceed the EPA level concern 37.5 ppb of atrazine + hydroxyatrazine in

sediment. The concentrations of atrazine + hydroxyatrazine exceed the EPA level of concern for 27 samples from 14 sites. The highest % of violation (60%, 3 out of 5 samples exceed 37.5 ppb of atrazine + hydroxyatrazine conc.) was found in two locations: Rock Quarry, Amistad Lake, TX and Canon Grande Creek, Eagle Pass, TX. The highest concentration of 652 μg/L was found in Bibe, Castolon, TX with a 42.8% (3 out of 7 samples exceed 37.5 ppb of atrazine + hydroxyatrazine conc.) violation. Atrazine entrained in sediment can pose a long-lasting threat to both water and soil quality in the Rio Grande Region.

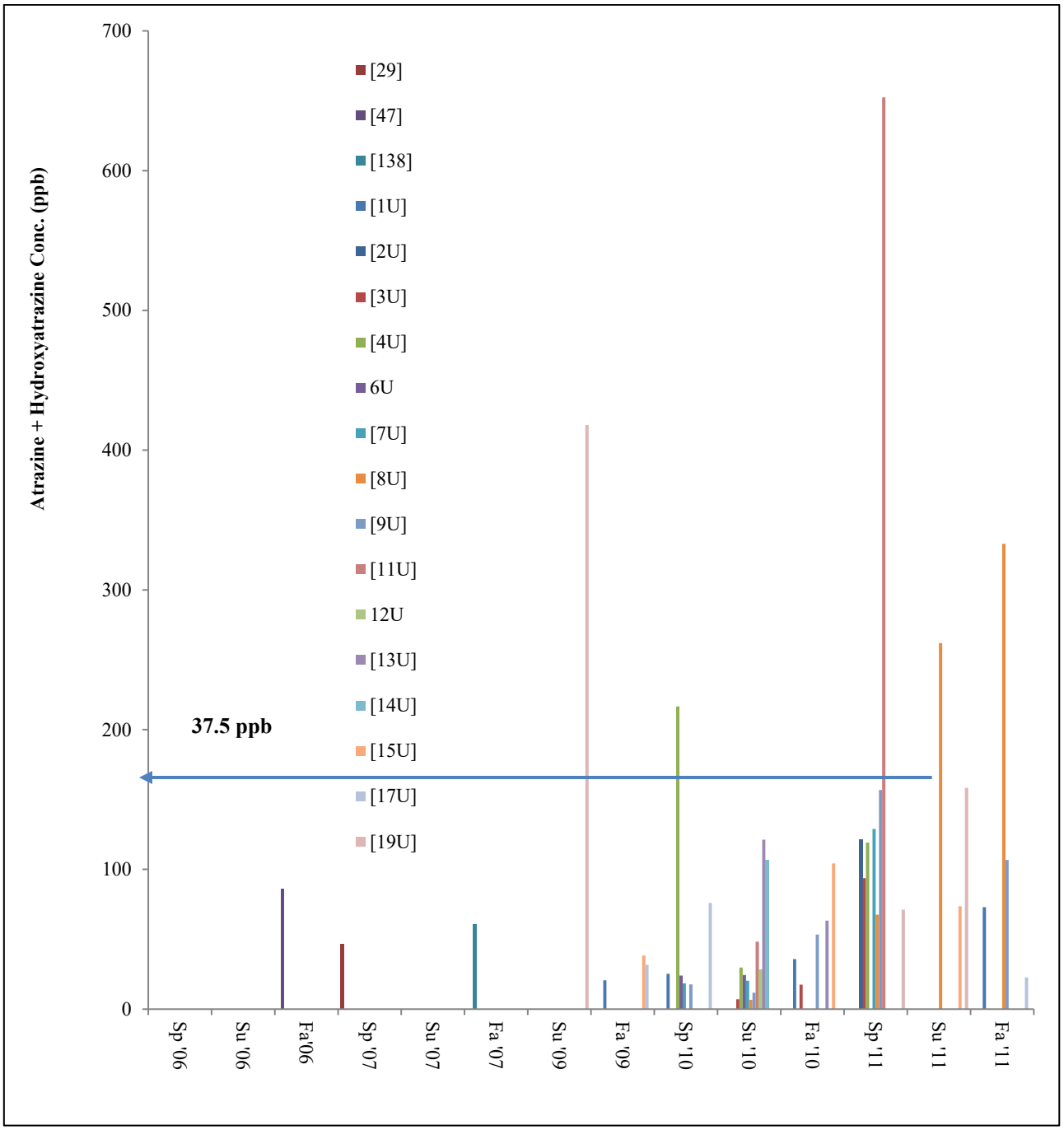

Fig. 7 Annual variations of atrazine + hydroxyatrazine analysis for the sediment samples collected from the Rio Grande region. [ ] indicates the sites which exceed the EPA level of concern (37.5 ppb of atrazine + hydroxyatrazine); during Sp '06-Sp '10 only atrazine was analyzed.

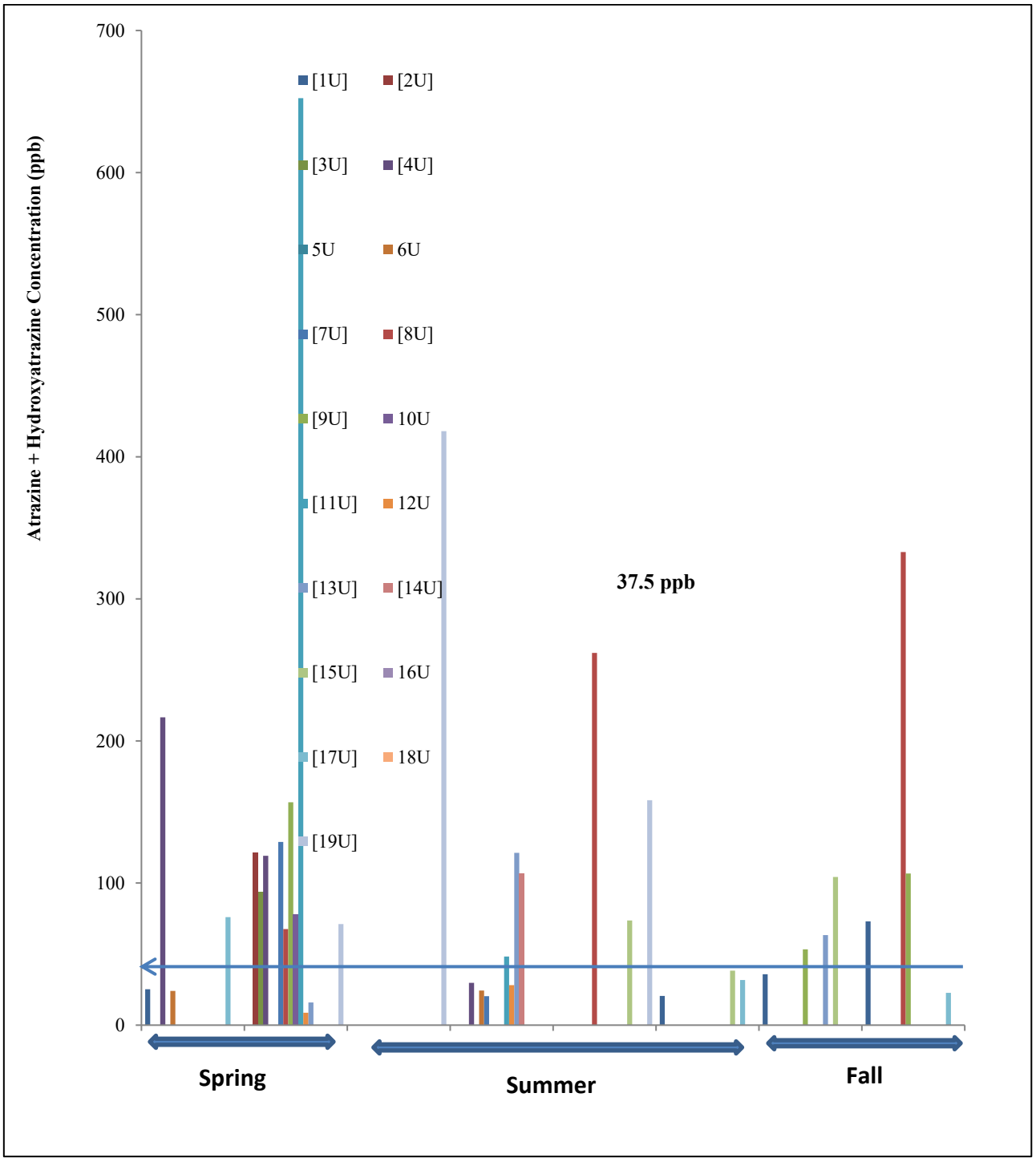

Fig. 8 Seasonal variation of atrazine + hydroxyatrazine analysis for the sediment samples collected from the Rio Grande region. [ ] indicates the sites which exceed the EPA level of concern (37.5 ppb of atrazine + hydroxyatrazine concentration).

Fig. 9 Map showing the site locations for sediment samples exceeding the EPA level of concern (37.5 ppb of atrazine + hydroxyatrazine).

5.3 Analysis of Atrazine in Sediment with Solvent Extraction

The amount of atrazine in sediment was found experimentally by extracting the sediment with dichloromethane/acetone 65: 35 v/v as solvent using the Soxhlet hot solvent extraction method [14]. 20 g of the sediment sample containing atrazine was placed inside a thimble made from thick filter paper, which was loaded into the main chamber of the Soxhlet extractor. The Soxhlet extractor was placed onto a flask containing the 120 mL of extraction solvent dichloromethane/acetone, 65:35 v/v. The Soxhlet was equipped with a condenser. The solvent was heated to reflux with level 2 temperatures. The solvent vapour traveled up a distillation arm, and flooded into the

chamber housing the thimble of solid. The condenser ensured that any solvent vapour cooled, and dripped back down into the chamber housing the solid material. This was repaeted to ensure that all atrazine was extracted. The extract was boiled upto 5 mL. The concentrated extract were then dried gently; the residue was mixed with 1 ml of acetonitrile and analyzed with HPLC to determine the amount of atrazine.

5.4 Chemical Analysis versus Soil Sorption Coefficient Correlation

Soil/Sediment Sorption Coefficient is given by Chen and Lyman, Reehl, and Rosenblatt [15, 16]:

$$\frac{x}{m} = K_{OC} * C \quad (1)$$

where x = Weight of solute sorbed, mg;

C = equilibrium concentration of solute in aqueous phase, mg/L;

m = weight of sorbent (organic carbon in soil), kg;

K_{OC} = Soil sorption Coefficient (L/kg) for atrazine = 149 L/kg.

The soil sorption coefficient, K_{OC}, determines the partitioning of an organic chemical between the soil/ sediment and the aqueous solution. Soil sorption coefficient is widely used in river, runoff, and soil/ground models for the assessments of the fate and transport of chemicals. With the value of K_{OC} known, the partition uptake of water contaminants for a particular soil/sediment or the degree of leaching of the pollutants in to the ground water can be estimated. The K_{OC} value for atrazine is 149 ((mg sorbed /kg organic carbon)/(mg/L of aqueous concentration)) [15, 16]. The amount of atrazine entrained in the sediment can be calculated by knowing the concentration of atrazine in water which is in equilibrium with adsorbed atrazine in sediment.

Therefore, by using the K_{OC} of atrazine, the aqueous concentration in equilibrium with adsorbed atrazine in sediment, and measured organic carbon content in the sediment, the amount of atrazine adsorbed on the sediment can be determined. The sediment samples were sent to Chemtex Industrial and Environmetal Hygeine Services, Sulphur, Louisiana to measure the TOC (Total Organic Carbon) content by the Walkley-Black method [17].

Amount of atrazine entrained in the sediment can be calculated with the soil sorption coefficient correlation to confirm the data experimentally determined by the Soxhlet hot solvent extraction method, Table 2. The comparison, Fig. 10 shows the comparison between the experimental and estimated atrazine sorbed on the sediment samples as given in Table 2. The diagonal line, y = x, is the reference line for estimated values equal to the experimental values. As can be seen, there is a good agreement between the two sets of values given in Table 2 with $R^2 = 0.986$.

Table 2 Comparison of atrazine extracted from sediment samples using the Soxhlet hot solvent extraction method and atrazine in sediment calculated using the soil sorption coefficient.

Site No.	Location	Abr. city	City	County	State	Season/year	TOC (%)	Atrazine calculated with K_{OC} (mg atrazine / kg of sediment)	Atrazine measured with solvent extraction (mg atrazine / kg of sediment)
4U	Dirt ditch behind dairy	Vado	Vado	Dona Ana	New Mexico	Summer 2010	1.16	0.374	0.335
6U	Gauging station	Cand	Candelaria	Persidio	Texas	Summer 2010	0.44	0.016	0.019
17U	Creek upper at cattle ranch	Edsn	Edison	Zavala	Texas	Summer 2010	5.27	0.597	0.527
4U	Dirt ditch behind dairy	Vado	Vado	Dona Ana	New Mexico	Fall 2010	1.16	0.051	0.059
13U	Langtry	Lngty	Langtry	Val Verde	Texas	Fall 2010	0.27	0.049	0.070
8U	Gauging station	NPers	N.Persidio	Persidio	Texas	Spring 2011	0.65	0.039	0.073

Table 2 to be continued

15U	Rock quarry	AmLk	Amistad lake	Val Verde	Texas	Summer 2011	5.35	0.587	0.548
8U	Gauging station	NPers	N.Persidio	Persidio	Texas	Fall 2011	0.65	0.32	0.31
17U	Creek upper at cattle ranch	Edsn	Edison	Zavala	Texas	Fall 2011	5.27	0.20	0.23

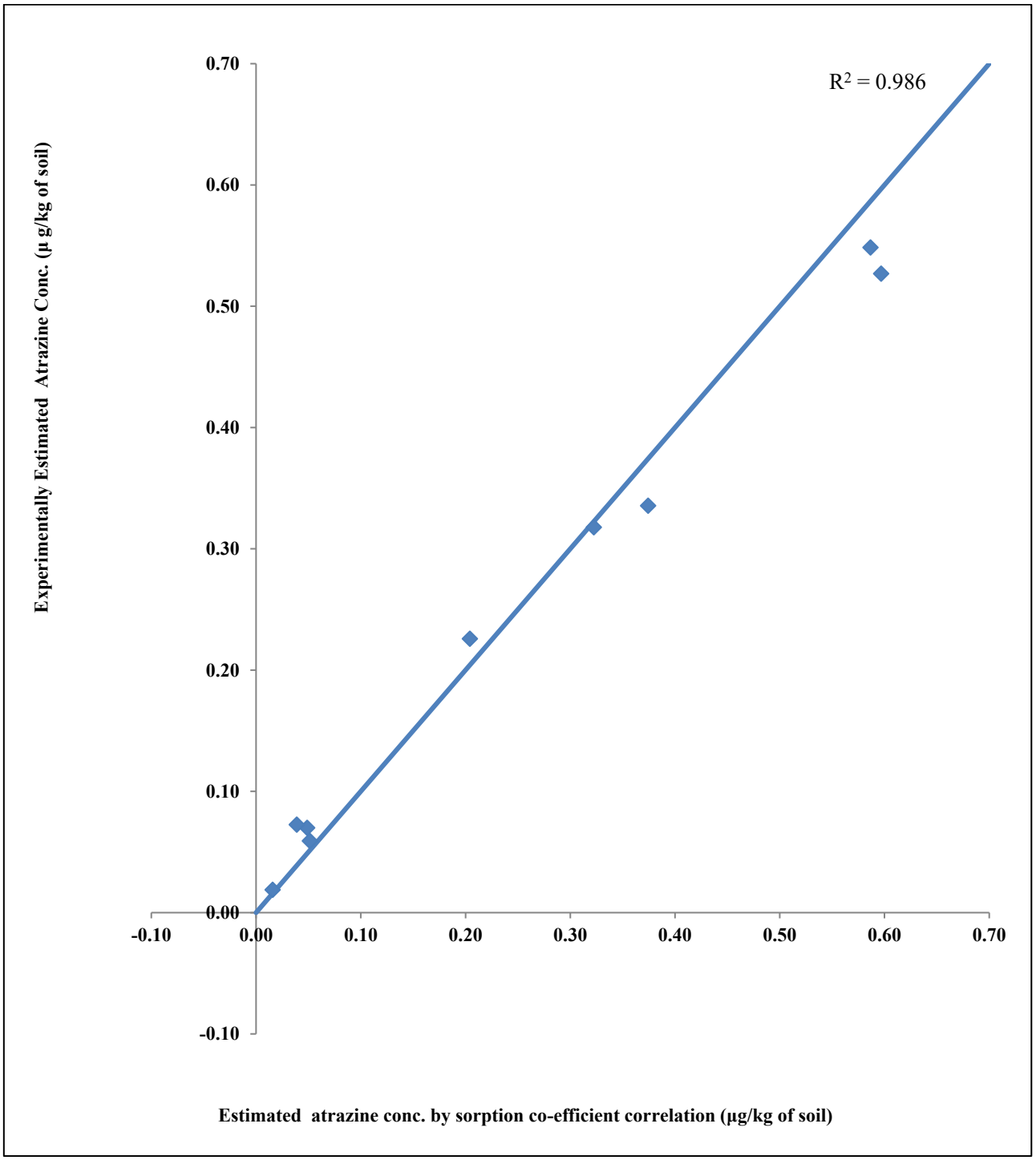

Fig. 10 Calculation vs. experimental for atrazine sorbed on sediments from Koc correlation & measurement (estimated = experimental is shown as the blue reference line; R^2 is given for the correlation and data).

6. Conclusions

Water and sediment samples collected from the Rio Grande Drainage Basin were analyzed for atrazine, an herbicide, and hydroxyatrazine, its primary degradation product, using HPLC (High Performance Liquid Chromotography). The geographical, seasonal, and annual distributions of the contamination were determined and the sites where collected water/sediment samples were above EPA's level of concern (> 37.5 ppb) were identified. The atrazine entrained in the sediment was extracted by the Soxhlet hot solvent extraction with dichloromethane/acetone 65:35 v/v solvent followed by the HPLC analysis. The amount of atrazine sorbed on sediment was also calculated using the soil sorption coefficient correlation. The geographical distributions of contamination (atrazine and its degradation product in water and sediment) are shown in maps. The seasonal distribution of atrazine contamination for all expeditions was also presented. Atrazine + hydroxyatrazine concentrations appear to increase from 2006 to 2011. Atrazine entrained in sediment sometimes exceeds the EPA levels of concern and can pose a long-term threat to the both water and soil quality in the Rio Grande Basin. Peak concentrations for atrazine in sediment are likely to be in summer season.

References

[1] Environment Protection Agency, Washington, DC. 2003. "Ambient Aquatic Life Water Quality Criteria for Atrazine-Revised Draft; EPA-822-R-03-023."

[2] Environment Protection Agency website. n.d. "Consumer Factsheet on: Atrazine, Part of National Primary Drinking Water Regulations." Accessed May 2006. http://www.epa.gov/safewater/dwh/c-soc/atrazine.html.

[3] Hayes, T., Haston, K., Tsui, M., Hoang, A., Haeffele, C., and Vonk, A. 2003. "Atrazine-Induced Hermaphroditism at 0.1 ppb in American Leopard Frogs (Ranapipiens): Laboratory and Field Evidence." *Environ. Health Persp.* 111 (4): 568-75.

[4] U.S. Environmental Protection Agency. 2011. "Pesticides: Atrazine Evaluation Process." http://www.epa.gov/oppsrrd1/reregistration/atrazine/atrazine_update.htm Last updated September.

[5] Environmental Protection Agency. October 7, 2009. "Atrazine Science Reevaluation: Potential Health Impacts, EPA-HQ-OPP-2009- 0759."

[6] Environmental Protection Agency. 2003. "Interim Reregistration Eligibility Decision (IRED)."

[7] Environmental Protection Agency. 2003. "Safe Drinking Water Act (SDWA)."

[8] Amsterdam. 1996. "Aquatic Outlook: An Analysis of Issues Pertaining to Aquatic Environments (Pesticides); Netherlands Ministry of Environment (Riza) Policy, Document 97.038."

[9] Texas Center for Policy Studies; Atrazine Contamination of Texas Drinking Water: Your Right-To-Know. 1999.

[10] Jones, L. 2003. "Texas Commission on Environmental Quality: Dealing with Atrazine." *Natural Outlook.*

[11] Ye, X., Chen, D. H., Li, K., Wang, B., and Hopper, J. 2006. "Photolytic Treatment of Atrazine-Contaminated Water: Products, Kinetics and Reactor Design." *J. Wat. Environ. Res.* 92: 1-10.

[12] Hang, S., Barriosu, E., and Houot, S. 2005. "Atrazine Behaviour in the Different Pedological Horizons of Two Argentinean Non-till Soil Profiles." *Weed Research* 45 (2): 130-9.

[13] Celis, R., Cornejo, J., Hermosı´n, M. C., and Koskinen, W. C. 1997. "Sorption-Desorption of Atrazine and Simazine by Model Soil Colloidal Components." *Soil Science Society of American Journal* 61: 436-43.

[14] Hrdlicka, A., and Dolinova, J. 2001. "Automated Hot Solvent Extraction and HPLC Determination of Atrazine and Its Degradation Products in Soil." *Journal of Liquid Chromatography and Related Technology* 24 (5): 721-34.

[15] Chen, D. H. 1999. *Chemical Properties Hankbook, Soil Sorption Coefficient*, edited by Yaws, C. New York: McGraw-Hill.

[16] Lyman, W. J., Reehl, W. F., and Rosenblatt, D. H. 1982. *Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds.* New York: McGraw-Hill.

[17] Page, A. L. July 1996. *Walkley-Black Methods of Soil Analysis, Part 2* (2nd ed.).