RESEARCH AND DEVELOPMENT REPORT

ECOM-0381-6

EVALUATION OF ATMOSPHERIC TRANSPORT AND DIFFUSION

SEMI-ANNUAL REPORT

By

Tom E. Sanford, Principal Investigator

July 1971

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DEPARTMENTS OF METEOROLOGY AND OCEANOGRAPHY

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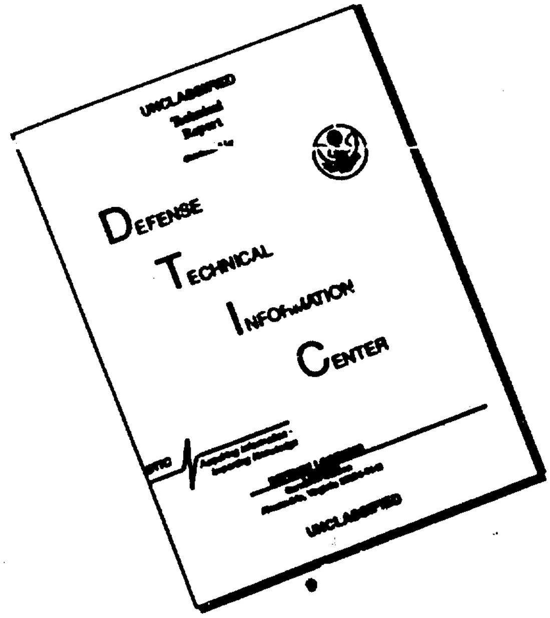

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I. INTRODUCTION

A complete set of tentatively scaled equations with the corresponding analog solution diagrams describing the temporal variation of winds, temperatures, vapor pressures, and heat fluxes within and above a tropical forest were set forth in Technical Report ECOM-0381-4. The potentiometer settings and static check calculations required for setting the computer up for simulation of those equations were included in Technical Report ECOM-0381-5.

In this report a set of scaled equations and the analog solution diagrams which describe the temporal variation of concentrations of trace elements in the simulated vertical column are described along with the conversions of the data required for set up and check out of the solutions on the analog computer.

II. SCALED ANALOG FORMAT OF THE EQUATIONS OF TRACE ELEMENT CONCENTRATION

A. Scaled Equations

For the initial stage in the development of a model for transport and diffusion within and above a tropical forest, the diffusion in a single vertical column only is being considered. The equations expressing the temporal variation of trace element concentration within the column are considered to be composed primarily of an advection term and a turbulent transport term. Within the forest itself a small absorption term has been added to the equations to account for chemical decomposition, absorption by foliage, and other losses within the forest proper. Above the forest no attempt is made to account for losses of trace materials resulting from these factors.

In an atmospheric layer of thickness ΔZ_j for which the mean height is Z_j, let χ_j be the mean concentration of trace element, u_j and v_j be, respectively, the mean east-west and north-south components of wind and $(\partial\chi/\partial x)_j$ and $(\partial\chi/\partial y)_j$ be, respectively, the mean gradients of trace element in the east-west and north-south directions. Further, let the mean flux of trace element at the top of the layer be $q_{d,k}$ and at the base of the layer be $q_{d,i}$. The scaled equations for mean concentration of trace element may then be written with this symbology in the following manner.

LEVEL = 250 m

$$\left(\frac{\chi_{250}}{10}\right) = -\int_{o}^{t'} \left[\frac{u_{250} \left(\frac{\partial \chi}{\partial x}\right)_{250} + v_{250} \left(\frac{\partial \chi}{\partial y}\right)_{250}}{.006944} + \frac{28.8}{\Delta Z_{250}} \left(\frac{q_{d,300}}{.2} - \frac{q_{d,200}}{.2}\right) \right] dt' + \left(\frac{\chi_{250}}{10}\right)_{t'=0} \quad (1)$$

LEVEL = 150 m

$$\left(\frac{\chi_{150}}{10}\right) = -\int_{o}^{t'} \left[\frac{u_{150} \left(\frac{\partial \chi}{\partial x}\right)_{150} + v_{150} \left(\frac{\partial \chi}{\partial y}\right)_{150}}{.006944} + \frac{28.8}{\Delta Z_{150}} \left(\frac{q_{d,200}}{.2} - \frac{q_{d,100}}{.2}\right) \right] dt' + \left(\frac{\chi_{150}}{10}\right)_{t'=0} \quad (2)$$

LEVEL = 75 m

$$\left(\frac{\chi_{75}}{10}\right) = -\int_{o}^{t'} \left[\frac{u_{75} \left(\frac{\partial \chi}{\partial x}\right)_{75} + v_{75} \left(\frac{\partial \chi}{\partial y}\right)_{75}}{.006944} + \frac{28.8}{\Delta Z_{75}} \left(\frac{q_{d,100}}{.2} - \frac{q_{d,50}}{.2}\right) \right] dt' + \left(\frac{\chi_{75}}{10}\right)_{t'=0} \quad (3)$$

LEVEL = 45 m

$$\left(\frac{\chi_{45}}{10}\right) = -\int_0^{t'} \left[\frac{u_{45} \left(\frac{\partial \chi}{\partial x}\right)_{45} + v_{45} \left(\frac{\partial \chi}{\partial y}\right)_{45}}{.006944} + \frac{28.8}{\Delta Z_{45}} \left(\frac{q_{d,50}}{.2} - \frac{q_{d,40}}{.2}\right) \right] dt' + \left(\frac{\chi_{45}}{10}\right)_{t'=0} \quad (4)$$

LEVEL = 35 m

$$\left(\frac{\chi_{35}}{10}\right) = -\int_0^{t'} \left[\frac{u_{35} \left(\frac{\partial \chi}{\partial x}\right)_{35} + v_{35} \left(\frac{\partial \chi}{\partial y}\right)_{35}}{.006944} + \frac{28.8}{\Delta Z_{35}} \left(\frac{q_{d,40}}{.2} - \frac{q_{d,30}}{.2}\right) + 1440 d'_{35} \left(\frac{\chi_{35}}{10}\right) \right] dt' + \left(\frac{\chi_{35}}{10}\right)_{t'=0} \quad (5)$$

LEVEL = 15 m

$$\left(\frac{\chi_{15}}{10}\right) = -\int_0^{t'} \left[\frac{u_{15} \left(\frac{\partial \chi}{\partial x}\right)_{15} + v_{15} \left(\frac{\partial \chi}{\partial y}\right)_{15}}{.006944} + \frac{28.8}{\Delta Z_{15}} \left(\frac{q_{d,30}}{.2} - \frac{q_{d,3}}{.2}\right) + 1440 d'_{15} \left(\frac{\chi_{15}}{10}\right) \right] dt' + \left(\frac{\chi_{15}}{10}\right)_{t'=0} \quad (6)$$

LEVEL = 1.5 m

$$\left(\frac{\chi_{1.5}}{10}\right) = -\int_0^{t'} \left[\frac{u_{1.5}\left(\frac{\partial\chi}{\partial x}\right)_{1.5} + v_{1.5}\left(\frac{\partial\chi}{\partial y}\right)_{1.5}}{.006944}\right.$$

$$\left. + \frac{28.8}{\Delta Z_{1.5}}\left(\frac{q_{d,3}}{.2} - \frac{q_{d,0}}{.2}\right) + 1440 d'_{15}\left(\frac{\chi_{1.5}}{10}\right)\right] dt' + \left(\frac{\chi_{1.5}}{10}\right)_{t'=0} \qquad (7)$$

where the computer time, t', is 1/1440 of real time, t, and the units employed are meters, kilograms, and seconds.

The analog form of the flux of trace element (in mg $m^{-2}sec^{-1}$) associated with each layer in the atmospheric column is

$$\frac{\left(\frac{q_{d,300}}{.2}\right)}{\left(\frac{K_{m,45}}{5}\right)} = \frac{\left(\frac{q_{d,200}}{.2}\right)}{\left(\frac{K_{m,45}}{5}\right)} + 25\left[\frac{K_{d,300}}{K_{m,45}}\left(\frac{\partial\chi}{\partial z}\right)_{300} - \frac{K_{d,200}}{K_{m,45}}\left(\frac{\partial\chi}{\partial z}\right)_{200}\right] \qquad (8)$$

$$\frac{\left(\frac{q_{d,200}}{.2}\right)}{\left(\frac{K_{m,45}}{5}\right)} = -\frac{250}{Z_{250} - Z_{150}}\left(\frac{K_{d,200}}{K_{m,45}}\right)\left(\frac{\chi_{250}}{10} - \frac{\chi_{150}}{10}\right) \qquad (9)$$

$$\frac{\left(\frac{q_{d,100}}{.2}\right)}{\frac{K_{m,45}}{5}} = -\frac{250}{Z_{150} - Z_{75}}\left(\frac{K_{d,100}}{K_{m,45}}\right)\left(\frac{\chi_{150}}{10} - \frac{\chi_{75}}{10}\right) \qquad (10)$$

$$\frac{\left(\frac{q_{d,50}}{.2}\right)}{\frac{K_{m,45}}{5}} = -\frac{250}{Z_{75} - Z_{45}}\left(\frac{K_{d,50}}{K_{m,45}}\right)\left(\frac{\chi_{75}}{10} - \frac{\chi_{45}}{10}\right) \qquad (11)$$

$$\frac{\left(\frac{q_{d,40}}{.2}\right)}{\left(\frac{K_{m,45}}{5}\right)} = - \frac{250}{Z_{40}\ \ln\left(\frac{Z_{45}}{Z_{35}}\right)} \left(\frac{K_{d,40}}{K_{m,45}}\right)\left(\frac{X_{45}}{10} - \frac{X_{35}}{10}\right) \tag{12}$$

$$\frac{\left(\frac{q_{d,30}}{.2}\right)}{\left(\frac{K_{m,30}}{5}\right)} = - \frac{250}{Z_{35} - Z_{15}} \left(\frac{K_{d,30}}{K_{m,30}}\right)\left(\frac{X_{35}}{10} - \frac{X_{15}}{10}\right) \tag{13}$$

$$\frac{\left(\frac{q_{d,3}}{.2}\right)}{\left(\frac{K_{m,3}}{5}\right)} = - \frac{250}{Z_{15} - Z_{1.5}} \left(\frac{K_{d,3}}{K_{m,3}}\right)\left(\frac{X_{15}}{10} - \frac{X_{1.5}}{10}\right) \tag{14}$$

$$\frac{\left(\frac{q_{d,0}}{.2}\right)}{\left(\frac{D_{1.5}}{.1}\right)} = - 5 \left(\frac{K_d}{K_m}\right)\left(\frac{X_{1.5} - X_0}{10}\right) \tag{15}$$

where $K_{m,45}$ is the exchange coefficient for momentum transport in $m^2 sec^{-1}$ at 45 m height. Similarly, $K_{m,3}$ and $K_{m,30}$ are the exchange coefficients for momentum at 3 and 30 m, respectively. The symbol $K_{d,j}$, where j = 1.5, 3, 30, 40, 50, 100, 200 or 300 m, represents the exchange coefficient for the turbulent mixing of the tracer element, X_j. The symbol $D_{1.5}$ is an integral exchange coefficient for energy transport within the forest surface layer, and Z_j, where j = 1.5, 15, 35, 40, 45, 75, 150 and 250m, represents the height in meters given by the value of the subscript j. The coefficient for depletion of trace elements, d_j', is applied at only the inforest levels of j = 1.5, 15, and 35 m.

B. Boundary Conditions

The upper boundary condition for the system of equations representing the effluent concentration is $\partial q_d/\partial z$ = constant. As an initial trial this constant will be assumed to be the value of $\partial q_d/\partial z$ calculated at the initial time for the layer centered at 250 m height. This value is then held constant at the initial value throughout the simulation period. Application of this boundary condition to the equation for the 250 m level permits calculation of the flux of the tracer element at the 300 m level as a function of that at the 200 m level. The relation is

$$q_{d,300} = q_{d,200} + K_{d,300} \left(\frac{\partial \chi}{\partial z}\right)_{300} - K_{d,200} \left(\frac{\partial \chi}{\partial z}\right)_{200}$$

where $q_{d,200}$ and $q_{d,300}$ are the fluxes of the trace element at the respective levels of 200 m and 300 m; $K_{d,200}$ and $K_{d,300}$ are the coefficients of turbulent transfer for the tracer element at 200 and 300 m; and $(\partial \chi/\partial z)_{200}$ and $(\partial \chi/\partial z)_{300}$ are the vertical gradients of tracer element concentration at 200 and 300 m height. This boundary condition will permit the addition or removal of tracer element through the upper boundary at any rate specified or initially determined.

At the lower boundary the concentration of the trace element may be specified as a constant or the functional form of its temporal variation may be specified. Until more knowledge is gained the simplest approach of specifying the surface concentration as constant will be employed.

III. ANALOG SOLUTION DIAGRAMS FOR THE EQUATIONS OF TRACE ELEMENT CONCENTRATION

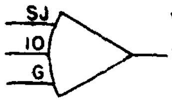
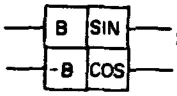
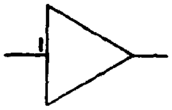
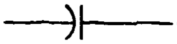
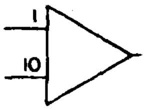
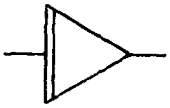
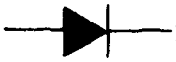
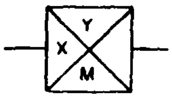
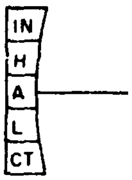
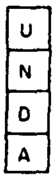
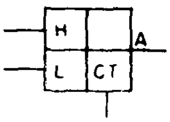
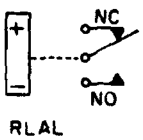
The analog solution diagrams for trace elements are shown on pages 10 through 12. Efforts have been made in constructing the solution diagrams to treat each parameter as a variable as far as is possible with the computing equipment available. The values of these variables may be changed easily from case to case, although for a particular case, the variable may be assigned a constant value.

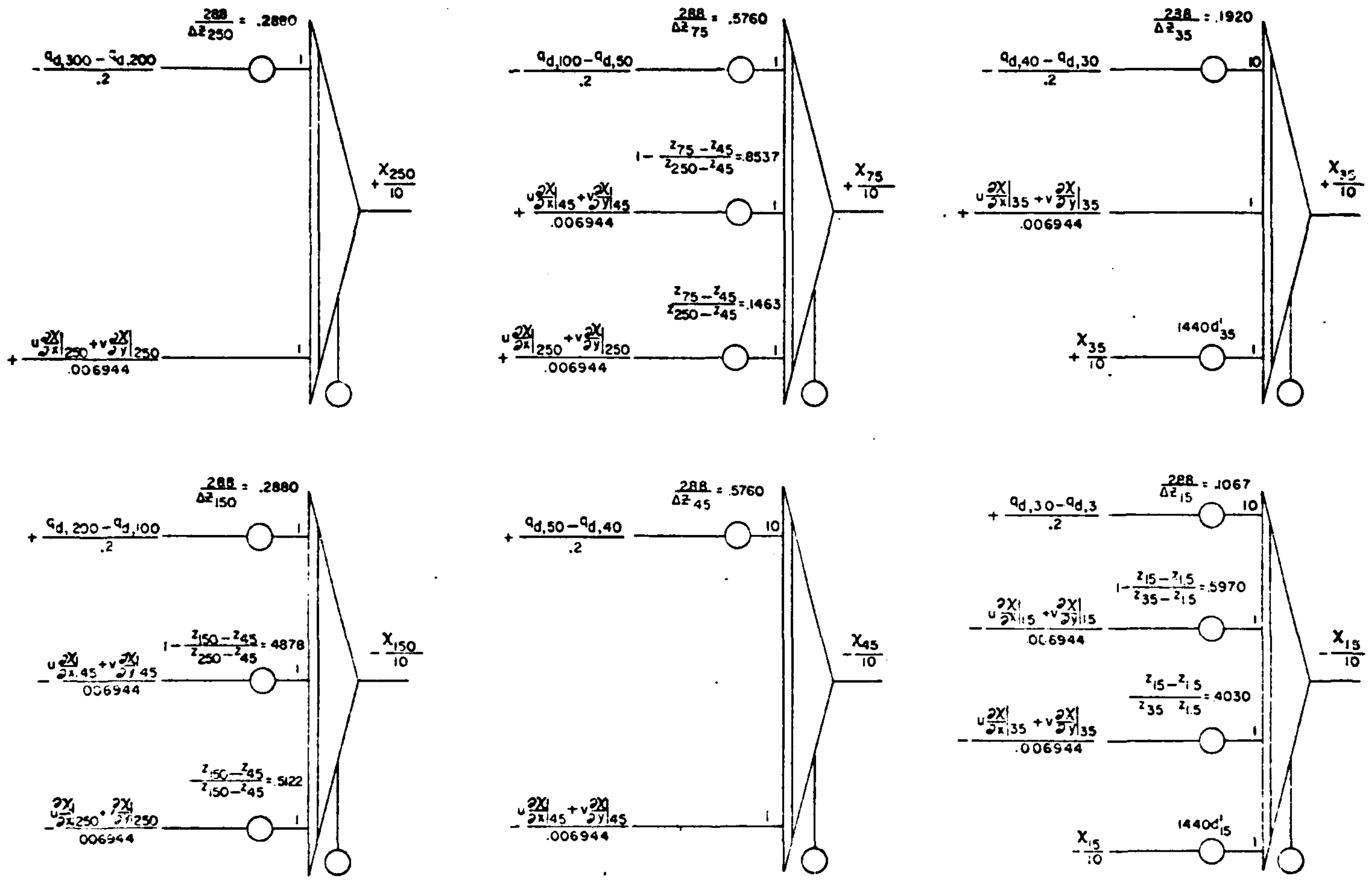
Due to the fact that much duplication in the type of circuitry employed is present (almost every level employs parallel designed circuitry) a complete discussion of each circuit will not be attempted; however, a brief explanation of the solution for a level which is characteristic of all solutions will be given in order to assist the reader in making the correspondence for solutions at other levels.

The symbols employed in the analog diagrams and their interpretation are shown in the table which appears on the following page.

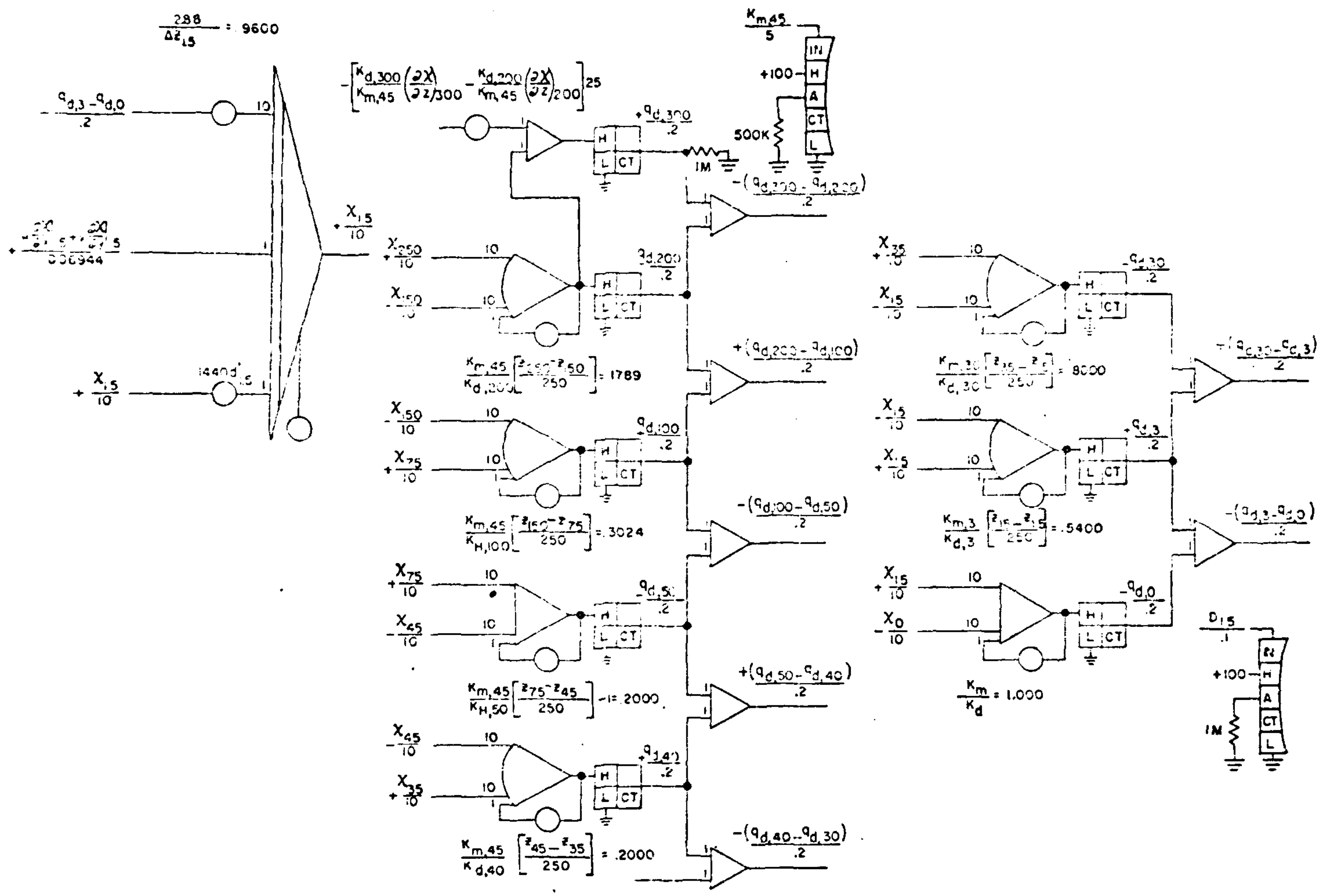
As an example of the circuitry used, consider the solution for the trace element concentration at 15 m height. The scaled value of the trace element concentration, $-\chi_{15}/10$, is obtained as the output of an integrator which sums the individual terms appearing on the right hand side of the equation for $-\chi_{15}/10$. The concentration is applied to the integrator through the initial condition potentiometer. The time varying inputs to the integrator consist of the advection, flux divergence, and depletion terms. These inputs are calculated in the following way.

ANALOG WIRING SYMBOLS

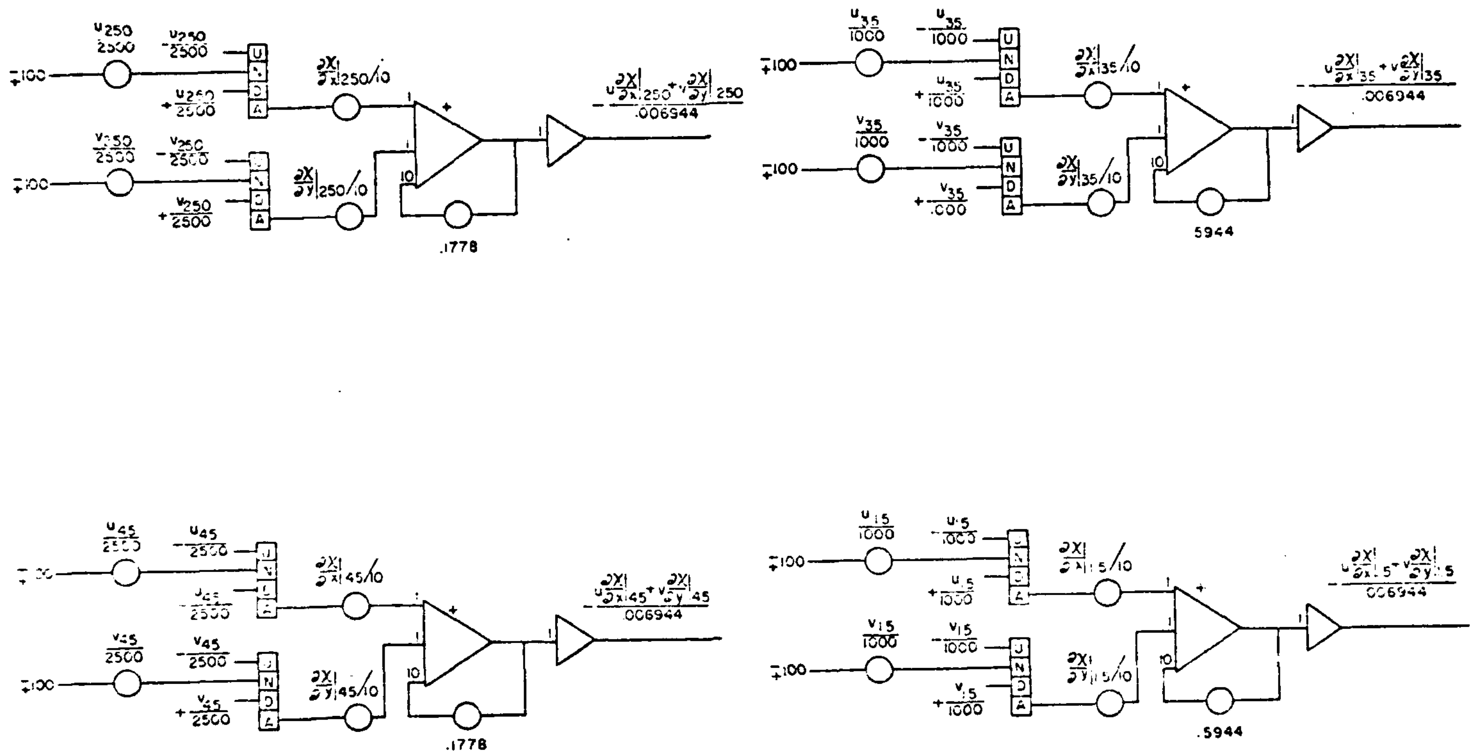
Symbol	Description	Symbol	Description
	High gain amplifier with an input to the summing junction, an input resistor of .1 megohm, an input directly to the grid, and no feedback		Servo resolver cup
	Inverter		Capacitor
	High gain amplifier with one megohm feed-back resistor and inputs of 1.0 and .1 megohm (summer)		Variable function generator
	Integrator		Resistor
	Potentiometer (low side grounded)		Diode
	Electronic multiplier		Ground
	Follow-up cup of a servo multiplier or resolver		Function switch
	Servo multiplier cup (other than follow-up)		Low speed relay comparator



TRACE ELEMENT CONCENTRATION



FLUX OF TRACE ELEMENTS



$\frac{\partial X}{\partial x}$ IS IN mg m^{-3} km^{-1}

ADVECTION OF TRACE ELEMENT CONCENTRATION

1. Advection of tracer element. Advection of the tracer element is calculated for the layers with mean heights of 1.5 m, 35 m, 45 m, and 250 m. Advection for levels between these layers is obtained by linear interpolation. Due to the fact that linear interpolation is used at 15-m height, two advection inputs to the $-\chi_{15}/10$ integrator are required to obtain the proper weighting of advection at 1.5 m and 35 m. The calculation of advection at each of the four levels is shown on page 12. Consider the level of 35 m only. Positive and negative values of the east-west and north-south wind components are applied independently to two function switches. The up position of the first function switch is connected to $-u_{35}/1000$ and the down position of the switch is connected to $+u_{35}/1000$. The arm of the first function switch is connected to a potentiometer having a setting of $(\partial\chi/\partial x)_{35}/10$; therefore, the voltage appearing on the arm of this potentiometer represents $-(u_{35}/1000)(\partial\chi/\partial x)_{35}/10$ or $+(u_{35}/1000)(\partial\chi/\partial x)_{35}/10$ depending upon whether the function switch is in the up position or in the down position. Similarly, the up position of the second function switch results in the calculation of $-(v_{35}/1000)(\partial\chi/\partial y)_{35}/10$ at the arm of the potentiometer. The down position of this switch merely selects the opposite sign of the same function. These two terms are further added in a summing amplifier and multiplied by the appropriate gain reduction of 1/6.944 to obtain the scaled value of the advection, $\frac{u\ \partial\chi/\partial x|_{35} + v\ \partial\chi/\partial y|_{35}}{.006944}$.

The neutral positions of the function switches are wired individually to the arms of two potentiometers. The initial values of the wind are set on the potentiometers so that advection may be held constant at the initial value throughout the solution period. Whether advection is held fixed at the initial value or allowed to vary with wind speed, the gradients of trace element are held constant throughout the solution period.

Advection at 1.5 m height is determined in an analogous manner as that at 35 m. These two components of the advection are multiplied by the appropriate interpolation factors appearing on potentiometers of which the arms are connected to unity gain inputs on the $-\chi_{15}/10$ integrator to provide linear interpolation between 1.5 m and 35 m height.

2. Vertical divergence of trace element concentration. Calculation of the vertical divergence of the trace element concentration appears in the upper right-hand corner of page 11. Voltages from the $+\chi_{35}/10$ and $-\chi_{15}/10$ integrators are applied individually to 10-gain* inputs of a high-gain amplifier having as a feedback element a potentiometer set to $(Z_{35} - Z_{15})\ K_{m,30}/250\ K_{d,30}$. The output of this high-gain amplifier represents $-q_{d,30}/K_{m,30}$ which is further multiplied by $+K_{m,30}/5$ by means of a servo-multiplier. The resulting product, $-q_{d,30}/.2$, is taken from the arm of the

*All amplifiers employed in the solution diagrams are of the inverting type; therefore, the term gain of one or gain of 10 implies a change in sign within the amplifier.

servo-multiplier. The flux at 3 m is obtained in a similar manner, and the resulting values of $- q_{d,30}/.2$ and $+ q_{d,3}/.2$ are added by a summing amplifier to obtain the difference of the fluxes at the two levels. This difference is further multiplied by $2.88/\Delta Z_{15}$ set on a potentiometer and applied to an input gain of one of the $- \chi_{15}/10$ integrator.

3. Depletion of trace concentration. Calculation of trace concentration depletion is accomplished simply by connecting a potentiometer, set to the depletion coefficient between the output and the input of the integrator. Initially depletion rates will be assumed to be directly proportional to the concentration.

IV. CONVERSION OF DATA TO GENERAL PURPOSE ANALOG COMPUTER INPUTS AND STATIC CHECK VOLTAGES

A. Calculation of Potentiometer and Function Switch Settings

Forms for computing and recording the potentiometer settings for the basic forest model excluding trace element concentration were included in Technical Report No. ECOM-0381-5. Consequently, this report contains only the pages on which these additional potentiometer settings appear. Since these potentiometer setting sheets are worksheets to be used for calculation, the additional potentiometer settings have been simply entered in the appropriate spaces in the worksheet and the complete page has been reproduced.

The forms are essentially self explanatory in that the calculations for the setting of each potentiometer are indicated. The forms for computing the potentiometer settings, beginning on page 18, contain five columns of which the first contains the number of the potentiometer under consideration for the computer console indicated by the number in the upper right-hand corner of each page. The second column contains the sign of the voltage applied to the potentiometer. Three symbols are used: + indicates that the + 100 v reference voltage is applied to the potentiometer; - indicates that the - 100 v reference voltage is applied to the potentiometer; and N indicates that the voltage polarity switch on the potentiometer is set to the neutral position so that the potentiometer may be used as a multiplying coefficient.

The settings computed for the individual potentiometers from the coefficient appearing in the fourth column are entered in the column headed "Setting".

The Notes Column contains comments regarding the application of a particular potentiometer or instructions for the computer operator. For example, the comment DIAL implies that the potentiometer is set according to the reading on the dial of the potentiometer rather than by the normal means of setting the potentiometer by the voltage at the arm of the potentiometer as read with a digital voltmeter. The notes IC and FB mean, respectively, that the potentiometer is used to supply an initial condition voltage or as a feedback element.

Accompanying the potentiometer settings for each console is a form on which the position of each function switch is indicated. The switch positions are either up, neutral, or down depending upon the value of the parameter in the column headed "Function". The function switch positions for Console 4 only are shown; however, function switches 9 and 10 on Consoles 1, 2, and 3, respectively, are used for selecting the algebraic signs for the gradients of trace element concentration at the heights of 250, 45, and 35 m.

CONSOLE 4

Pot	Sign	Setting	Coefficient	Notes
000			$+ e_{250}/100$	IC
001	N	.0449	$\frac{.72p_{250}}{\rho La\ \Delta z_{250}} (\frac{K_{m,300}}{K_{m,200}} - 1)$	
002	N		$1440d'_{35}$	
003	N	.5122	$(z_{150} - z_{45})/(z_{250} - z_{45})$	
004	N	.0958	$\frac{p_{250}(z_{250} - z_{150})}{10^7\ \rho La} (\frac{K_{m,45}}{K_{m,200}})$	FB
005	N		$(\partial e/\partial x)_{250}$	
006			$-\left\|(u_{250}/2500)(u \frac{\partial e}{\partial x})_{250}\right\|/(u \frac{\partial e}{\partial x})_{250}$	Set with FS 6 in N
007	N	.0120	$(p_{150}/p_{250}) - 1$	
008			$25 [\frac{K_{d,300}}{K_{m,45}}(\frac{\partial \chi}{\partial z})_{300} - \frac{K_{d,200}}{K_{m,45}}(\frac{\partial \chi}{\partial z})_{200}]$	
009			$- \chi_{250}/10$	IC
010			$- e_{150}/100$	IC
011	N	.1619	$.72p_{150}/\rho La\ \Delta z_{150}$	
012	N		$1440d'_{15}$	
013	N	.4878	$1 - \frac{z_{150} - z_{45}}{z_{250} - z_{45}}$	
014	N	.1566	$\frac{p_{150}\ (z_{150} - z_{75})}{10^7\ \rho La} (\frac{K_{m,45}}{K_{m,100}})$	FB
015	N		$(\partial e/\partial y)_{250}$	
016			$-\left\|(v_{250}/2500)(v \frac{\partial e}{\partial v})_{250}\right\|/(v \frac{\partial e}{\partial y})_{250}$	Set with FS 16 in N
017	N	.0089	$(p_{75}/p_{150}) - 1$	
018	N	.1789	$(Z_{250} - Z_{150})\ K_{m,45}/250\ K_{d,200}$	FB

CONSOLE 4

Pot	Sign	Setting	Coefficient	Notes
019			$+ X_{150}/10$	IC
020			$+ e_{75}/100$	IC
021	N	.3267	$.72p_{75}/\rho La\ \Delta z_{75}$	
022			$M_{1.5}/100$	
023	N	.1463	$\frac{z_{75} - z_{45}}{z_{250} - z_{45}}$	
024	N	.3436	$\frac{p_{75}\ (z_{75} - z_{45})}{10^7\ \rho La} (\frac{K_{m,45}}{K_{m,50}})$	FB
025	N		$(\partial e/\partial x)_{45}$	
026			$-\left\| (u_{45}/2500)(u\ \frac{\partial e}{\partial x})_{45} \right\| / (u\ \frac{\partial e}{\partial x})_{45}$	Set with FS 3 in N
027	N	.0036	$(p_{45}/p_{75}) - 1$	
028	N	.3024	$(Z_{150} - Z_{75})\ K_{m,45}/250\ K_{d,100}$	FB
029			$- X_{75}/10$	IC
030			$- e_{45}/100$	IC
031	N	.1639	$.072p_{45}/\rho La\ \Delta z_{45}$	
032			$(373.2/p) - 1/10$	
033	N	.8537	$1 - \frac{z_{75} - z_{45}}{z_{250} - z_{45}}$	
034	N	.1139	$\frac{p_{40}\ (z_{45} - z_{40})}{10^7\ \rho La}$	FB
035	N		$(\partial e/\partial y)_{45}$	
036			$-\left\| (v_{45}/2500)(v\ \frac{\partial e}{\partial y})_{45} \right\| / (v\ \frac{\partial e}{\partial y})_{45}$	Set with FS 4 in N
037	N	.0006	$(p_{40}/p_{45}) - 1$	

CONSOLE 4

Pot	Sign	Setting	Coefficient	Notes
038	N	.2000	$[(Z_{75} - Z_{45}) K_{m,45}/250 K_{d,50}] - 1$	FB
039			$+ X_{45}/10$	IC
040			$- e_{35}/100$	IC
041	N	.1641	$.072p_{35}/\rho La \Delta z_{45}$	
042	N		$M_{35}/10M_{1.5}$	
043	N	.4030	$\frac{z_{15} - z_{1.5}}{z_{35} - z_{1.5}}$	
044	N	.1139	$\frac{p_{40} (z_{40} - z_{35})}{10^7 \rho L}$	FB
045	N		$(\partial e/\partial x)_{35}$	
046			$- \left\| (u_{35}/1000)(u \frac{\partial e}{\partial x})_{35} \right\| /(u \frac{\partial e}{\partial x})_{35}$	Set with FS 5 in N
047	N	.0006	$(p_{35}/p_{40}) - 1$	
048	N	.2000	$(Z_{45} - Z_{35}) K_{m,45}/250 K_{d,40}$	FB
049			$- X_{35}/10$	IC
050			$+ e_{15}/100$	IC
051	N	.6093	$.72p_{15}/\rho La \Delta z_{15}$	
052	N		$M_{15}/10M_{1.5}$	
053	N	.5970	$1 - \frac{z_{15} - z_{1.5}}{z_{35} - z_{1.5}}$	
054	N	.4559	$\frac{p_{35} (z_{35} - z_{15})}{10^7 \rho aL}$	FB
055	N		$(\partial e/\partial y)_{35}$	
056			$- \left\| (v_{35}/1000)(v \frac{\partial e}{\partial y})_{35} \right\| /(v \frac{\partial e}{\partial y})_{35}$	Set with FS 6 in N

CONSOLE 4

Pot	Sign	Setting	Coefficient	Notes
057	N	.0023	$(p_{15}/p_{35}) - 1$	
058	N	.8000	$(Z_{35} - Z_{15})\ K_{m,30}/250\ K_{d,30}$	FB
059			$+\ X_{15}/10$	IC
060			$-\ e_{1.5}/100$	IC
061	N	.5493	$.072p_{1.5}/\rho La\ \Delta z_{1.5}$	
062	N	.1000	1/10	
063	N		$1440d'_{1.5}$	
064	N	.3085	$\frac{p_{15}\ (z_{15} - z_{1.5})}{10^7\ \rho aL}$	FB
065	N		$(\partial e/\partial x)_{1.5}$	
066			$-\left\|(u_{1.5}/1000)(u\ \frac{\partial e}{\partial y})_{1.5}\right\|/(u\ \frac{\partial e}{\partial y})_{1.5}$	Set with FS 7 in N
067	N	.0016	$(p_{1.5}/p_{15}) - 1$	
068	N	.5400	$(Z_{15} - Z_{1.5})\ K_{m,3}/250\ K_{d,3}$	FB
069			$-\ X_{1.5}/10$	IC
070	N	.6000	6/10	
071				
072				
073	N	.5944	$[(1/1440)/1000 \times 10^{-6}] - 1/10$	FB
074	N	.1445	$(p_o/2000\ \rho aL) - 1$	FB
075	N		$(\partial e/\partial y)_{1.5}$	
076			$-\left\|(v_{1.5}/1000)(v\ \frac{\partial e}{\partial y})_{1.5}\right\|/(v\ \frac{\partial e}{\partial y})_{1.5}$	Set with FS 8 in N
077	N	.0002	$(p_o/p_{1.5}) - 1$	

CONSOLE 4

Pot	Sign	Setting	Coefficient	Notes
078	N	.2000	$0.2\ K_m/K_d$	FB
079	N	.5760	$2.88/\Delta Z_{45}$	
080				
081	N	.1778	$[10^6/(2500)(1440)] - 1/10$	FB
082	N	.1778	$[10^6/(2500)(1440)] - 1/10$	FB
083	N	.5944	$[10^6/(1000)(1440)] - 1/10$	FB
084	N	.5944	$[10^6/(1000)(1440)] - 1/10$	FB
085	N	.1778	$[(1/1440)/2500 \times 10^{-6}] - 1/10$	FB
086	N	.4878	$1 - (Z_{150} - Z_{45})/(Z_{250} - Z_{45})$	
087	N	.1463	$(Z_{75} - Z_{45})/(Z_{250} - Z_{45})$	
088	N	.2880	$28.8/\Delta Z_{250}$	
089	N	.1920	$2.88/\Delta Z_{35}$	
090				
091	N		$\partial\chi/\partial x\|_{250}/10$	
092	N		$\partial\chi/\partial y\|_{250}/10$	
093	N		$\partial\chi/\partial x\|_{45}/10$	
094	N		$\partial\chi/\partial y\|_{45}/10$	
095	N	.1778	$[(1/1440)/2500 \times 10^{-6}] - 1/10$	FB
096	N	.5122	$(Z_{150} - Z_{45})/(Z_{250} - Z_{45})$	
097	N	.5970	$1 - (Z_{15} - Z_{1.5})/(Z_{35} - Z_{1.5})$	
098	N	.2880	$28.8/\Delta Z_{150}$	
099	N	.1067	$2.88/\Delta Z_{15}$	
100				
101	N		$\partial\chi/\partial x\|_{35}/10$	

CONSOLE 4

Pot	Sign	Setting	Coefficient	Notes
102	N		$\partial\chi/\partial y\|_{35}/10$	
103	N		$\partial\chi/\partial x\|_{1.5}/10$	
104	N		$\partial\chi/\partial v\|_{1.5}/10$	
105	N	.5944	$[(1/1440)/1000 \times 10^{-6}] - 1/10$	FB
106	N	.8537	$1 - (Z_{75} - Z_{45})/(Z_{250} - Z_{45})$	
107	N	.4030	$(Z_{15} - Z_{1.5})/(Z_{35} - Z_{1.5})$	
108	N	.5760	$28.8/\Delta Z_{75}$	
109	N	.9600	$2.88/\Delta Z_{1.5}$	

FUNCTION SWITCH DESIGNATION

CONSOLE 4

Switch	Position	Function
1	u	$\left.\frac{\partial e}{\partial x}\right\|_{250} > 0$
	n	$u \left.\frac{\partial e}{\partial x}\right\|_{250} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial x}\right\|_{250} < 0$
2	u	$\left.\frac{\partial e}{\partial y}\right\|_{250} > 0$
	n	$v \left.\frac{\partial e}{\partial y}\right\|_{250} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial y}\right\|_{250} < 0$
3	u	$\left.\frac{\partial e}{\partial x}\right\|_{45} > 0$
	n	$u \left.\frac{\partial e}{\partial x}\right\|_{45} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial x}\right\|_{45} < 0$
4	u	$\left.\frac{\partial e}{\partial y}\right\|_{45} > 0$
	n	$v \left.\frac{\partial e}{\partial y}\right\|_{45} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial y}\right\|_{45} < 0$
5	u	$\left.\frac{\partial e}{\partial x}\right\|_{35} > 0$
	n	$u \left.\frac{\partial e}{\partial x}\right\|_{35} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial x}\right\|_{35} < 0$

CONSOLE 4

Switch	Position	Function
6	u	$\left.\frac{\partial e}{\partial y}\right\|_{35} > 0$
	n	$v \left.\frac{\partial e}{\partial y}\right\|_{35} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial y}\right\|_{35} < 0$
7	u	$\left.\frac{\partial e}{\partial x}\right\|_{1.5} > 0$
	n	$u \left.\frac{\partial e}{\partial x}\right\|_{1.5} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial x}\right\|_{1.5} < 0$
8	u	$\left.\frac{\partial e}{\partial y}\right\|_{1.5} > 0$
	n	$v \left.\frac{\partial e}{\partial y}\right\|_{1.5} = \text{constant}$
	d	$\left.\frac{\partial e}{\partial y}\right\|_{1.5} < 0$
9	u	$\left.\frac{\partial \chi}{\partial x}\right\|_{1.5} > 0$
	n	$u \left.\frac{\partial \chi}{\partial x}\right\|_{1.5} = \text{constant}$
	d	$\left.\frac{\partial \chi}{\partial x}\right\|_{1.5} < 0$
10	u	$\left.\frac{\partial \chi}{\partial v}\right\|_{1.5} > 0$
	n	$u \left.\frac{\partial \chi}{\partial y}\right\|_{1.5} = \text{constant}$
	d	$\left.\frac{\partial \chi}{\partial y}\right\|_{1.5} < 0$

B. Static Check Calculations

Flux of Trace Element

$$q_{d,0} = - D_{1.5} (K_{d,1.5}/K_{m,1.5})(\chi_{1.5} - \chi_0)$$

$$= - (\quad) (1) (\quad - \quad)$$

$$= \qquad mg\ m^{-2}\ sec^{-1}$$

$$q_{d,0} = \frac{mg\ m^{-2}\ sec^{-1}}{.002} = \qquad volts$$

$$q_{d,3} = - (\frac{1}{z_{15} - z_{1.5}}) K_{d,3} (\chi_{15} - \chi_{1.5})$$

$$= - (7.407 \times 10^{-2}) (\quad) (\quad - \quad)$$

$$= \qquad mg\ m^{-2}\ sec^{-1}$$

$$q_{d,3} = \frac{mg\ m^{-2}\ sec^{-1}}{.002} = \qquad volts$$

$$q_{d,30} = - (\frac{1}{z_{35} - z_{15}}) K_{d,30} (\chi_{35} - \chi_{15})$$

$$= - (5.0 \times 10^{-2}) (\quad) (\quad - \quad)$$

$$= \qquad mg\ m^{-2}\ sec^{-1}$$

$$q_{d,30} = \frac{\text{mg m}^{-2}\ \text{sec}^{-1}}{.002} = \qquad \text{volts}$$

$$q_{d,40} = - \left[\frac{1}{z_{40}\ \ln\ (\frac{z_{45}}{z_{35}})} \right] K_{d,40}\ (\chi_{45} - \chi_{35})$$

$$= - (9.948 \times 10^{-2})\ (\qquad)\ (\qquad - \qquad)$$

$$= \qquad \text{mg m}^{-2}\ \text{sec}^{-1}$$

$$q_{d,40} = \frac{\text{mg m}^{-2}\ \text{sec}^{-1}}{.002} = \qquad \text{volts}$$

$$q_{d,50} = - (\frac{1}{z_{75} - z_{45}})\ K_{d,50}\ (\chi_{75} - \chi_{45})$$

$$= - (3.333 \times 10^{-2})\ (\qquad)\ (\qquad - \qquad)$$

$$= \qquad \text{mg m}^{-2}\ \text{sec}^{-1}$$

$$q_{d,50} = \frac{\text{mg m}^{-2}\ \text{sec}^{-1}}{.002} = \qquad \text{volts}$$

$$q_{d,100} = - (\frac{1}{z_{150} - z_{75}})\ K_{d,100}\ (\chi_{150} - \chi_{75})$$

$$= - (1.333 \times 10^{-2})\ (\qquad)\ (\qquad - \qquad)$$

$$= \qquad\qquad\qquad\qquad \text{mg m}^{-2}\ \text{sec}^{-1}$$

$$q_{d,100} = \frac{\text{mg m}^{-2}\ \text{sec}^{-1}}{.002} = \qquad\qquad\qquad \text{volts}$$

$$q_{d,200} = -\left(\frac{1}{z_{250} - z_{150}}\right) K_{d,200} (X_{250} - X_{150})$$

$$= -(1.0 \times 10^{-2})\ (\qquad\quad)\ (\qquad - \qquad)$$

$$= \qquad\qquad\qquad\qquad \text{mg m}^{-2}\ \text{sec}^{-1}$$

$$q_{d,200} = \frac{\text{mg m}^{-2}\ \text{sec}^{-1}}{.002} = \qquad\qquad\qquad \text{volts}$$

$$q_{d,300} = q_{d,200} + K_{d,300} \left(\frac{X_{350} - X_{250}}{z_{350} - z_{250}}\right) - K_{d,200} \left(\frac{X_{250} - X_{150}}{z_{250} - z_{150}}\right)$$

$$= (\qquad\quad) + (\qquad\quad) \left[\frac{(\qquad\quad) - (\qquad\quad)}{(\qquad\quad) - (\qquad\quad)}\right]$$

$$- (\qquad\quad) \left[\frac{(\qquad\quad) - (\qquad\quad)}{(\qquad\quad) - (\qquad\quad)}\right]$$

$$= \qquad\qquad\qquad\qquad \text{mg m}^{-2}\ \text{sec}^{-1}$$

$$q_{d,300} = \frac{\text{mg m}^{-2}\ \text{sec}^{-1}}{.002} = \qquad\qquad\qquad \text{volts}$$

Advection of Trace Element

$$u_{1.5}\left(\frac{\partial \chi}{\partial x}\right)_{1.5} + v_{1.5}\left(\frac{\partial \chi}{\partial y}\right)_{1.5}^{*} = (\qquad)(\qquad) + (\qquad)(\qquad)$$

$$= \qquad\qquad \text{mg m}^{-3}\ \text{sec}^{-1}$$

$$= \frac{\text{mg m}^{-3}\ \text{sec}^{-1}}{6.944} = \qquad\qquad \text{volts}$$

$$u_{35}\left(\frac{\partial \chi}{\partial x}\right)_{35} + v_{35}\left(\frac{\partial \chi}{\partial y}\right)_{35} = (\qquad)(\qquad) + (\qquad)(\qquad)$$

$$= \qquad\qquad \text{mg m}^{-3}\ \text{sec}^{-1}$$

$$= \frac{\text{mg m}^{-3}\ \text{sec}^{-1}}{6.944} = \qquad\qquad \text{volts}$$

$$u_{45}\left(\frac{\partial \chi}{\partial x}\right)_{45} + v_{45}\left(\frac{\partial \chi}{\partial y}\right)_{45} = (\qquad)(\qquad) + (\qquad)(\qquad)$$

$$= \qquad\qquad \text{mg m}^{-3}\ \text{sec}^{-1}$$

$$= \frac{\text{mg m}^{-3}\ \text{sec}^{-1}}{6.944} = \qquad\qquad \text{volts}$$

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* $(\partial\chi/\partial x)_j$ and $(\partial\chi/\partial y)_j$ have units = mg m^{-3} km^{-1}

$$u_{250} \left(\frac{\partial \chi}{\partial x}\right)_{250} + v_{250} \left(\frac{\partial \chi}{\partial y}\right)_{250} = (\qquad)(\qquad) + (\qquad)(\qquad)$$

$$= \qquad\qquad \text{mg m}^{-3}\ \text{sec}^{-1}$$

$$= \frac{\text{mg m}^{-3}\ \text{sec}^{-1}}{6.944} = \qquad\qquad \text{volts}$$

Static Check Voltages

Parameter	Value	Units	Conversion Factor (Units/Volt)	Voltage	C O N	Element
$+ \chi_{250}$		mg/m^3	+ .1000		4	A27
$- \chi_{150}$		mg/m^3	- .1000		4	A36
$+ \chi_{75}$		mg/m^3	+ .1000		4	A38
$- \chi_{45}$		mg/m^3	- .1000		4	A49
$+ \chi_{35}$		mg/m^3	+ .1000		4	A51
$- \chi_{15}$		mg/m^3	- .1000		4	A57
$+ \chi_{1.5}$		mg/m^3	+ .1000		4	A59
$+ q_{d,300}$		mg/m^2 sec	+ .002		4	S07
$- q_{d,200}$		mg/m^2 sec	- .002		4	S08
$+ q_{d,100}$		mg/m^2 sec	+ .002		4	S09
$- q_{d,50}$		mg/m^2 sec	- .002		4	S10
$+ q_{d,40}$		mg/m^2 sec	+ .002		4	S11
$- q_{d,30}$		mg/m^2 sec	- .002		4	S13
$+ q_{d,3}$		mg/m^2 sec	+ .002		1	S23
$- q_{d,0}$		mg/m^2 sec	- .002		1	S31
$-(u\frac{\partial\chi}{\partial x}\Big\vert_{250} + v\frac{\partial\chi}{\partial y}\Big\vert_{250})$		mg/m^3 sec	6.944		4	A06
$-(u\frac{\partial\chi}{\partial x}\Big\vert_{45} + v\frac{\partial\chi}{\partial x}\Big\vert_{45}$		mg/m^3 sec	6.944		4	A07

Parameter	Value	Units	Conversion Factor (Units/Volt)	Voltage	CON	Element
$-(u\frac{\partial\chi}{\partial x}\Big\vert_{35} + v\frac{\partial\chi}{\partial y}\Big\vert_{35})$		mg/m^3 sec	6.944		4	A10
$-(u\frac{\partial\chi}{\partial x}\Big\vert_{1.5} + v\frac{\partial\chi}{\partial x}\Big\vert_{1.5})$		mg/m^3 sec	6.944		4	A29