UCH QATLAMLI G‘OVAK MUHITLARDA BOSIMLI VA BOSIMSIZ SUVLARNING BEQAROR HARAKATINING MATEMATIK MODELI.

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Annotatsiya. Mazkur maqolada uch qatlamli g‘ovak muhitlarda bosimli va bosimsiz suvlarning beqaror harakatining matematik modeli qurilgan. Model A.N. Myatiev va N.K. Girinskiy gipotezalariga asoslanib, o‘tkazuvchan va kam o‘tkazuvchan qatlamlararo suv oqimi xususiyatlari hisobga olingan. Chekli ayirmalar usuli va progonka algoritmi yordamida sonli yechimlar ishlab chiqilgan. Hisoblash natijalari asosida sizot va bosimli suvlarning harakat dinamikasi tahlil qilinib, amaliy prognozlar uchun samarali dasturiy ta’minot ishlab chiqilgan.

Kalit so‘zlar: g‘ovak muhit, bosimli suv, bosimsiz suv, matematik model, filtratsiya, sonli usul, chekli ayirmalar, progonka usuli.

Аннотация. В данной статье разработана математическая модель неустановившегося движения напорных и безнапорных вод в трёхслойной пористой среде. Модель основана на гипотезах А.Н. Мятиева и Н.К. Гиринского, учитывая особенности водного потока между проницаемыми и малопроницаемыми слоями. С использованием метода конечных разностей и алгоритма прогонки получены численные решения. На основе расчётных результатов проведён анализ динамики движения грунтовых и напорных вод и разработано эффективное программное обеспечение для практических прогнозов.

Ключевые слова: пористая среда, напорные воды, безнапорные воды, математическая модель, фильтрация, численный метод, конечные разности, метод прогонки.

Abstract. This article develops a mathematical model for the unsteady flow of confined and unconfined groundwater in a three-layer porous medium. The model is based on the hypotheses of A.N. Myatiev and N.K. Girinskiy, considering the flow characteristics between permeable and low-permeability layers. Numerical solutions are obtained using the finite difference method and the Thomas algorithm. Based on the computational results, the dynamics of groundwater and confined water movement are analyzed, and efficient software for practical forecasting is developed.

Keywords: porous medium, confined water, unconfined water, mathematical model, filtration, numerical method, finite differences, Thomas algorithm.

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Bizning respublikamizda filtratsiya nazariyasi bo‘yicha olib borilayotgan tadqiqotlar, yer osti suvlarining darajasi o‘zgarishini to‘g‘ri prognoz qilish va sun'iy va tabiiy drenaj tizimlarining yer osti suvlarining darajasiga ta'sirini baholash masalalari maxsus ahamiyatga ega. Shuningdek, bosimli suvlarning harakati gidrogeologiya, melioratsiya va tuproqshunoslik uchun juda muhimdir.

Ma'lumki, yer osti suvlarining ko‘tarilishi turli sabablarga ko‘ra atrof-muhitga salbiy ta'sir ko‘rsatadi. Bu yuzaki tuproqlarning sho‘rlanishiga, ortiqcha sug‘orishga, yer osti suvlarining rejimi va balansining o‘zgarishiga, qishloq xo‘jaligi ekinlarini sug‘orishga va melioratsiya xo‘jaliklarini boshqarishga olib keladi. Shu sababli, yer osti suvlarining ekspluatatsiya zaxiralarini dinamik baholash kompleks tadqiqotlarga asoslanishi kerak, bu tadqiqotlar iqlim sharoitlarini, gidrotexnikani, melioratsiyani va suv ta'minotini hisobga olishi zarur.

Matematik model. Uch qatlamli bir jinsli bo‘lmagan qatlamda yer osti suvlari harakatining beqaror jarayonini ko‘rib chiqamiz. Bu qatlam quyidagilardan tashkil topgan: yuqori qismida erkin sathga ega bo‘lgan yer osti suvlari joylashgan kam o‘tkazuvchan qoplovchi qatlam; pastki qismida suv o‘tkazmaydigan qatlam bilan chegaralangan, o‘rtada esa yaxshi o‘tkazuvchan bosimli suv tutuvchi qatlam joylashgan.

A.N. Myatiev – N.K. Girinskiy gipotezasiga ko‘ra qatlamlar chegarasidagi oqim chiziqlari yaxshi o‘tkazuvchan qatlam tomonida gorizontalga yaqin, qoplovchi qatlam tomonida esa vertikalga yaqin shakllanadi. Shu sababli, qoplovchi qatlamdagi filtratsiya tezligining gorizontal tarkibiy qismlarini ularning juda kichikligi sababli e’tiborga olmaslik mumkin. Bug‘lanish jarayoniga nisbatan esa M.M. Krylov – S.F. Averyanov gipotezasi asosli deb qabul qilinadi.

Bundan tashqari, quduqlar faqat yaxshi o‘tkazuvchan bosimli qatlamdan foydalanadi, degan farazni qabul qilamiz.

Yuqoridagi farazlarga asoslangan holda, ko‘rib chiqilayotgan filtratsiya jarayoni quyidagi kvazichiziqli, xususiy hosilali differensial tenglamalar sistemasi bilan, ya’ni parabolik tipdagi tizim bilan ifodalanadi.

$$\begin{cases} \dfrac{\partial H}{\partial t} = \dfrac{\mu}{\mu_b T_x}\dfrac{\partial}{\partial x}\left[K_b H \dfrac{\partial H}{\partial x}\right] - \dfrac{\mu}{\mu_b}K_b\left(1-\dfrac{h_1}{H}\right) + \dfrac{\mu}{\mu_b}(f-w) \\ \dfrac{\partial h_1}{\partial t} = \dfrac{\partial}{\partial x}\left[T_1 \dfrac{\partial h_1}{\partial x}\right] + K_b\left(1-\dfrac{h_1}{H}\right) - \dfrac{K_\Pi}{h_\Pi}(h_2-h_1) - Q \\ \dfrac{\partial h_2}{\partial t} = \dfrac{\partial}{\partial x}\left[T_2 \dfrac{\partial h_2}{\partial x}\right] + \dfrac{K_\Pi}{h_\Pi}(h_2-h_1), \quad 0<x<L, \quad t>0. \end{cases} \qquad (3.1)$$

chegara shartlari bilan

ISSN 3030-3907

$$H(x,t_0)=F_1(x); \quad h_1(x,t_0)=F_2(x); \quad h_2(x,t_0)=F_3(x); \tag{3.2}$$

$$-k\frac{\partial H}{\partial x}=\alpha(H_A-H),\ x=0; \quad k\frac{\partial H}{\partial x}=\alpha(H_A-H),\ x=L \tag{3.3}$$

$$-k\frac{\partial h_1}{\partial x}=\alpha(h_A-h_1),\ x=0; \quad k\frac{\partial h_1}{\partial x}=\alpha(h_A-h_1),\ x=L \tag{3.4}$$

$$-k\frac{\partial h_2}{\partial x}=\alpha(h_A-h_2),\ x=0; \quad k\frac{\partial h_2}{\partial x}=\alpha(h_A-h_2),\ x=L \tag{3.5}$$

Bu yerda

H(x,t) – asosiy suv tutuvchi qatlam tomidagi grunt suvlarining erkin sathgacha bo‘lgan darajasi;

$h_1(x, t)$, $h_2(x, t)$ – asosiy suv tutuvchi qatlamning bosimlari (naporlari);

Kb(x) – qoplovchi qatlamning filtratsiya koeffitsienti;

$T_1(x) = K_1m$, $T_2(x) = K_2m$ – bosimli qatlamning suv o‘tkazuvchanlik koeffitsientlari;

m(x), K(x) – asosiy qatlamning quvvati, filtratsiya koeffitsienti va elastik suv beruvchanlik koeffitsienti;

– qoplovchi qatlamning suv beruvchanlik koeffitsienti yoki to‘yinish yetishmovchiligi;

f(x,t) – infiltratsiya funksiyasi;

w(x,t) – bug‘lanish.

Ko‘plab dala kuzatuvlari shuni ko‘rsatadiki, bug‘lanish grunt suvlarining chuqurligiga bog‘liq. M.M. Krylov va S.F. Averyanov bug‘lanish uchun quyidagi formula asosli deb hisoblashadi.

$$w=\begin{cases} w_0\left(\dfrac{H-H_{KP}}{m_B-H_{KP}}\right)^n; & H>H_{KP} \\ 0; & H\le H_{KP} \end{cases} \tag{3.6}$$

bu yerda w_0 – yer yuzasidan bug‘lanish miqdori (maksimal bug‘lanish);

HKP – kritik chuqurlik (grunt suvlarining bug‘lanishga ta’sir qilmaydigan eng katta chuqurligi);

n – parametr.

Qo‘yilgan chegara masalasi, noaniq (nolinelinear) hadlarni linearlashtirish uchun kvazilinearlashtirish usulidan foydalangan holda, chekli farqlar usuli yordamida yechiladi.

(1)-tenglama va (2)–(5) chegara shartlar tizimida o‘lchamsiz o‘zgaruvchilarga o‘tamiz.

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$$H^* = \frac{H}{H_x};\ h_1^* = \frac{h_1}{H_x};\ h_2^* = \frac{h_2}{H_x};\ h_\Pi^* = \frac{h_\Pi}{H_x};\ K_b^* = \frac{K_b}{K_x};\ K_\Pi^* = \frac{K_\Pi}{K_x};$$

$$T^* = \frac{T}{T_x};\ \tau = \frac{T_x t}{\mu L^2};\ x^* = \frac{x}{L}.$$

Bu yerda K_x, H_x, T_x – mos funksiyalarga tegishli ba'zi xarakterli (odatda maksimal yoki o‘rtacha) qiymatlar.

Yozuvni soddalashtirish maqsadida o‘lchamsiz o‘zgaruvchilar ustidagi yulduzcha belgilarni tashlab yuborsak, o‘lchamsiz ko‘rinishdagi differensial tenglamalar sistemasini olamiz:

$$\begin{cases} \dfrac{\partial H}{\partial \tau} = \dfrac{K_x \mu H_x}{\mu T_x}\dfrac{\partial}{\partial x}\left[K_b H \dfrac{\partial H}{\partial x}\right] - \dfrac{K_x \mu L^2}{\mu_b T_x H_x} K_b\left(1 - \dfrac{h_1}{H}\right) + \dfrac{\mu L^2}{\mu_b T_x H_x}(f - w) \\ \dfrac{\partial h_1}{\partial \tau} = \dfrac{\partial}{\partial x}\left[T_1 \dfrac{\partial h_1}{\partial x}\right] + \dfrac{K_x L^2}{T_x H_x} K_b\left(1 - \dfrac{h_1}{H}\right) - \dfrac{K_x L^2}{T_x H_x}\dfrac{K_\Pi}{h_\Pi}(h_2 - h_1) - \dfrac{K_x L^2}{T_x H_x} Q \\ \dfrac{\partial h_2}{\partial \tau} = \dfrac{\partial}{\partial x}\left[T_2 \dfrac{\partial h_2}{\partial x}\right] + \dfrac{K_x L^2}{T_x H_x}\dfrac{K_\Pi}{h_\Pi}(h_2 - h_1) \end{cases} \quad (3.7)$$

O‘lchamsiz masala (3.7) chegara shartlari (3.2) – (3.5) bilan chekli-ayirmalar usuli va oddiy iteratsiyalar yordamida yechiladi.

Sonli model va bosimli-bosimsiz filtratsiya masalalarini yechish algoritmini ishlab chiqish

Sonli model. Sonli yechim uchun chegara masalasi (3.7), (3.2) – (3.5) ni yechish maqsadida filtratsiya sohasida to‘rlarni quramiz:

$$D = \{0 \le x \le 1;\ \ 0 \le t \le T\}$$

$$\omega_{h\tau} = \left\{ x_i = ih,\ h = \frac{1}{N},\ t_l = l\tau,\ \tau = \frac{T}{M},\ i = 0,1,...,N,\ l = 0,1,2,...,M \right\}$$

Yozuvni soddalashtirish maqsadida, chekli-ayirmalar masalasi (3.7) shaklida quyidagi belgilashlarni kiritamiz:

$$v = \frac{K_x \mu H_x}{\mu_b T_x};\ v_1 = \frac{K_x \mu L^2}{\mu_b T_x H_x};\ v_2 = \frac{\mu L^2}{\mu_b T_x H_x};\ v_3 = \frac{K_x L^2}{T_x H_x};\ v_4 = \frac{K_x L^2}{T_x H_x}\frac{K_\Pi}{h_\Pi};$$

Belgilashlarni kiritgandan so‘ng, quyidagi tenglamalar tizimini olamiz:

$$\begin{cases} \dfrac{\partial H}{\partial \tau} = v\dfrac{\partial}{\partial x}\left[K_b H \dfrac{\partial H}{\partial x}\right] - v_1 K_b\left(1 - \dfrac{h_1}{H}\right) + v_2(f - w) \\ \dfrac{\partial h_1}{\partial \tau} = \dfrac{\partial}{\partial x}\left[T_1 \dfrac{\partial h_1}{\partial x}\right] + v_3 K_b\left(1 - \dfrac{h_1}{H}\right) - v_4(h_2 - h_1) - \dfrac{K_x L^2}{T_x H_x} Q \\ \dfrac{\partial h_2}{\partial \tau} = \dfrac{\partial}{\partial x}\left[T_2 \dfrac{\partial h_2}{\partial x}\right] + v_4(h_2 - h_1) \end{cases} \quad (3.8)$$

ISSN 3030-3907

Dastlabki va chegara shartlari quyidagi ko‘rinishda bo‘ladi:

$$H(x,0)=H_0;\quad h_1(x,0)=h_{10};\quad h_2(x,0)=h_{20};$$

(3.9)

$$-k\frac{\partial H(0,t)}{\partial x}=\alpha\left[H_A-H(0,t)\right];\quad k\frac{\partial H(1,t)}{\partial x}=\alpha\left[H_A-H(1,t)\right] \quad (3.10)$$

$$-k\frac{\partial h_1(0,t)}{\partial x}=\alpha\left[h_A-h_1(0,t)\right];\quad k\frac{\partial h_1(1,t)}{\partial x}=\alpha\left[h_A-h_1(1,t)\right] \quad (3.11)$$

$$-k\frac{\partial h_2(0,t)}{\partial x}=\alpha\left[h_A-h_2(0,t)\right];\quad k\frac{\partial h_2(1,t)}{\partial x}=\alpha\left[h_A-h_2(1,t)\right] \quad (3.12)$$

Agar (3.8) differensial tenglamalar sistemasini approksimatsiyalasak, unda chekli-ayirmalar tenglamasi l+1 -vaqt qatlami uchun quyidagi ko‘rinishga ega bo‘ladi:

$$H_i^{l+1}-H_i^l=v\frac{\Delta\tau}{\Delta x^2}\left[\frac{H_i^l+H_{i+1}^l}{2}\left(H_{i+1}^{l+1}-H_i^{l+1}\right)-\frac{H_{i-1}^l+H_i^l}{2}\left(H_i^{l+1}-H_{i-1}^{l+1}\right)\right]-$$

$$-v_1\left(1-\frac{h_{1i}^l}{H_i^l}\right)+v_2(f-w);$$

$$h_{1i}^{l+1}-h_{1i}^l=\frac{\Delta\tau}{\Delta x^2}T_1\left(h_{1i-1}^{l+1}-2h_{1i}^{l+1}+h_{1i+1}^{l+1}\right)+v_3\left(1-\frac{h_{1i}^l}{H_i^l}\right)-v_4\left(h_{2i}^l-h_{1i}^l\right)-Q;$$

$$h_{2i}^{l+1}-h_{2i}^l=\frac{\Delta\tau}{\Delta x^2}T_2\left(h_{2i-1}^{l+1}-2h_{2i}^{l+1}+h_{2i+1}^{l+1}\right)+v_4\left(h_{2i}^l-h_{1i}^l\right).$$

$$i=1,2,...,N-1.$$

Bu yerda:

H_i^l – grunt suvlarining l-vaqt qatlamidagi sathi;

H_i^{l+1} – grunt suvlarining l+1-vaqt qatlamidagi sathi;

h_{1i}^l – l-vaqt qatlamidagi bosim (napor);

h_{1i}^{l+1} – l+1-vaqt qatlamidagi bosim (napor);

h_{2i}^l – l-vaqt qatlamidagi bosim (napor);

h_{2i}^l – l+1-vaqt qatlamidagi bosim (napor).

Endi dastlabki va chegara shartlarni yondashamiz (ya’ni, ularni sonli ko‘rinishga keltiramiz).

$$H_i^{(0)}=H_0,\quad h_{1i}^{(0)}=h_{10},\quad h_{2i}^{(0)}=h_{20},\quad i=0,1,...,N. \quad (3.13)$$

$$-k\frac{H_0^{(l+1)}+H_1^{(l+1)}}{h}=\alpha\left(H_A-H_0^{(l+1)}\right),\quad k\frac{H_N^{(l+1)}-H_{N-1}^{(l+1)}}{h}=\alpha(H_A-H_N^{(l+1)}), \quad (3.14)$$

ISSN 3030-3907

$$-k\frac{h_{10}^{(l+1)}+h_{11}^{(l+1)}}{\Delta x}=\alpha\left(h_A-h_{10}^{(l+1)}\right),\quad k\frac{h_{1N}^{(l+1)}-h_{1N-1}^{(l+1)}}{\Delta x}=\alpha(h_A-h_{1N}^{(l+1)}),\qquad(3.15)$$

$$-k\frac{h_{20}^{(l+1)}+h_{21}^{(l+1)}}{\Delta x}=\alpha\left(h_A-h_{20}^{(l+1)}\right),\quad k\frac{h_{2N}^{(l+1)}-h_{2N-1}^{(l+1)}}{\Delta x}=\alpha(h_A-h_{2N}^{(l+1)}).\qquad(3.16)$$

Yondashgandan (approksimatsiyadan) so‘ng quyidagi uch nuqtali chekli-ayirmali tenglamalarini olamiz. Birinchi tenglama va uning chegara sharti quyidagi ko‘rinishda bo‘ladi:

$$\begin{gathered}(3k-2\Delta x\alpha)H_0^{(l+1)}-4kH_1^{(l+1)}+kH_2^{(l+1)}=2\Delta x\alpha H_A\\ A_iH_{i-1}^{(l+1)}-C_iH_i^{(l+1)}+B_iH_{i+1}^{(l+1)}=-F_i^j,\quad i=1,2,...,N-1\qquad(3.19)\\ (3k-2\Delta x\alpha)H_N^{(l+1)}+4kH_{N-1}^{(l+1)}-kH_{n-2}^{(l+1)}=-2\Delta x\alpha h_{1A}.\end{gathered}$$

Bu yerda:

$$A_i=\frac{v\Delta\tau}{\Delta x^2}a_iH_i^{(l)},\ B_i=\frac{v\Delta\tau}{\Delta x^2}a_{i+1}(H_i^{(l)}),\ C_i=\frac{v\Delta\tau}{\Delta x^2}\left[a_{i+1}(H_i^{(l)})+a_i(H_i^{(l)})\right]+1,$$

$$a_i(H_i^{(l)})=\frac{H_{i-1}^{(l)}+H_i^{(j)}}{2}$$

$$F_i=H_i^{(l)}-v_1(1-h_{1i}^{(l)}(H_i^{(l)}))+v_2(f-w)$$

Ikkinchi tenglama va uning chegara sharti quyidagi ko‘rinishda bo‘ladi:

$$\begin{gathered}(3k-2\Delta x\alpha)h_{10}^{(l+1)}-4kh_{11}^{(l+1)}+kh_{12}^{(l+1)}=2\Delta x\alpha h_{1A}\\ A_{1i}h_{1i-1}^{j+1}-C_{1i}h_{1i}^{j+1}+B_{1i}h_{1i+1}^{j+1}=-F_{1i}^j,\ i=1,2,...,N-1,\qquad(3.20)\\ (3k-2\Delta x\alpha)h_{1N}^{(l+1)}+4kh_{1N-1}^{(l+1)}-kh_{1N-2}^{(l+1)}=-2\Delta x\alpha h_{1A}.\end{gathered}$$

Bu yerda:

$$\begin{gathered}A_{1i}=\frac{T_1\Delta\tau}{\Delta x^2};\quad B_{1i}=\frac{T_1\Delta\tau}{\Delta x^2},\quad C_{1i}=\frac{2T_1\Delta\tau}{\Delta x^2}+1,\\ F_{1i}^{(l)}=h_{1i}^{(l)}+v_3\left[(1-h_{1i}^{(l)}(H_i^{(l)})-v_4(h_{2i}^{(l)}-h_{1i}^{)l)})\right]-Q;\end{gathered}$$

Uchinchi tenglama va uning chegara sharti quyidagi ko‘rinishda bo‘ladi:

$$\begin{gathered}(3k-2\Delta x\alpha)h_{20}^{(l+1)}-4kh_{21}^{(l+1)}+kh_{22}^{(l+1)}=2\Delta x\alpha h_{2A}\\ A_2h_{2i-1}^{(l+1)}-C_2h_{2i}^{(l+1)}+B_2h_{2i+1}^{(l+1)}=-F_{2i}^{(l)},\ i=1,2,...,N-1,\qquad(3.21)\\ (3k-2\Delta x\alpha)h_{2N}^{(l+1)}+4kh_{2N-1}^{(l+1)}-kh_{2N-2}^{(l+1)}=-2\Delta x\alpha h_{2A}.\end{gathered}$$

Bu yerda:

$$\begin{gathered}A_2=\frac{T_2\Delta\tau}{\Delta x^2};\quad B_2=\frac{T_2\Delta\tau}{\Delta x^2},\quad C_2=\frac{2T_2\Delta\tau}{\Delta x^2}+1,\\ F_{2i}^{(l)}=h_{2i}^{(l)}+v_4(h_{2i}^{(l)}-h_{1i}^{(l)}).\end{gathered}$$

Birinchi chekli-ayirmalar tenglamasini yechish uchun progonka usulidan (ya’ni, tridiagonal sistemani yechish usulidan) foydalanamiz.

ISSN 3030-3907

$$H_i^{(l+1)} = \alpha_{i+1} H_{i+1}^{(l+1)} + \beta_{i+1}, \qquad i = N-1, N-2, \ldots, 1, 0. \qquad (3.22)$$

Bu yerda progonka (oldinga-qaytish) koeffitsientlari quyidagi ko‘rinishga ega:

$$\alpha_{i+1} = \frac{\beta_i}{C_i - A_i \alpha_i}, \quad \beta_{i+1} = \frac{A\beta_i + F_i^{(l)}}{C_i - A_i \alpha_i}, \quad i = 1, 2, \ldots, N-1, \qquad (3.23)$$

Progonka koeffitsientlarining boshlang‘ich qiymatlari quyidagicha aniqlanadi:

$$H_0^{(l+1)} = \alpha_1 H_1^{(l+1)} + \beta_1$$

$$H_0^{(l+1)} - H_1^{(l+1)} = -\frac{\alpha \Delta x}{k} H_A + \frac{\alpha \Delta x}{k} H_0^{(l+1)}$$

$$(1 - \frac{\alpha \Delta x}{k}) H_0^{(l+1)} = H_1^{(l+1)} - \frac{\alpha \Delta x}{k} H_A$$

$$\frac{k - \alpha \Delta x}{k} H_0^{(l+1)} = H_1^{(l+1)} - \frac{\alpha \Delta x}{k} H_A \Rightarrow H_0^{(l+1)} = \frac{k}{k - \alpha \Delta x} H_1^{(l+1)} - \frac{\alpha \Delta x}{k - \alpha \Delta x} H_A$$

$$\alpha_1 = \frac{k}{k - \alpha \Delta x}, \ \beta_1 = \frac{\alpha \Delta x}{k - \alpha \Delta x} H_A$$

Bosimsiz suvlar funksiyasining yakuniy (oxirgi) qiymati quyidagicha aniqlanadi:

$$H_{N-1}^{(l+1)} = \alpha_N H_N^{(l+1)} + \beta_N, \quad H_N^{(l+1)} - H_{N-1}^{(l+1)} = \frac{\alpha x}{k}(H_B - H_N^{(l+1)}),$$

$$H_N^{(l+1)} - \alpha_N H_N^{(l+1)} - \beta_N = \frac{\alpha \Delta x}{k} H_B - \frac{\alpha \Delta x}{k} H_N^{(l+1)},$$

$$H_N^{(l+1)}(1 - \alpha_N + \frac{\alpha \Delta x}{k}) = \frac{\alpha \Delta x}{k} H_B + \beta_N,$$

$$H_N^{(l+1)} = \frac{\alpha \Delta x H_B / k + \beta_N}{1 - \alpha_N + \frac{\alpha \Delta x}{k}}.$$

Ikkinchi chekli-ayirmali tenglamasini yechish uchun ham progonka usulidan foydalanamiz.

$$h_{1i}^{(l+1)} = \alpha_{i+1}^{'} h_{1i+1}^{(l+1)} + \beta_{i+1}^{'}, \quad i = N-1, N-2, \ldots, 1, 0. \qquad (3.24)$$

Bu yerda progonka koeffitsientlari quyidagi ko‘rinishga ega:

$$\alpha_{i+1}^{'} = \frac{\beta_i^{'}}{C_1 - A_1 \alpha_i^{'}}, \ \beta_{i+1}^{'} = \frac{A_1 \beta_i^{'} + F_{1i}^{(l)}}{C_1 - A_1 \alpha_i^{'}}, \ i = 1, 2, \ldots, N-1. \qquad (3.25)$$

Progonka koeffitsientlarining boshlang‘ich qiymati va bosimli suvlar funksiyasining yakuniy qiymati quyidagicha aniqlanadi:

ISSN 3030-3907

$$\alpha_1^{'}=\frac{k}{k-\alpha\Delta x},\quad \beta_1^{'}=-\frac{\alpha\Delta x}{k-\alpha\Delta x}h_A,$$

$$h_{1N}^{(l+1)}=\frac{\alpha_N^{'}\Delta x h_A/k+\beta_N^{'}}{1-\alpha_N^{'}+\frac{\alpha_N^{'}\Delta x}{k}},$$

Uchinchi chekli-ayirmali tenglamasini yechish uchun ham progonka usulidan foydalanamiz.

$$h_{2i}^{(l+1)}=\alpha_{i+1}^{"}h_{2i+1}^{(l+1)}+\beta_{i+1}^{"},\ i=N-1,N-2,...,1,0.\text{n}\qquad(3.26)$$

Bu yerda progonka koeffitsientlari quyidagi ko‘rinishga ega:

$$\alpha_{i+1}^{"}=\frac{\beta_i^{"}}{C_2-A_2\alpha_i^{"}},\ \beta_{i+1}^{"}=\frac{A_2\beta_i^{"}+F_{2i}^{(l+1)}}{C_2-A_2\alpha_i^{"}},\ i=1,2,...,N-1.\qquad(3.27)$$

Progonka koeffitsientlarining boshlang‘ich qiymati va bosimli suvlar funksiyasining yakuniy qiymati quyidagicha aniqlanadi:

$$\alpha_1^{"}=\frac{k}{k-\alpha\Delta x},\quad \beta_1^{"}=-\frac{\alpha\Delta x}{k-\alpha\Delta x}h_B,$$

$$h_{2N}^{(l+1)}=\frac{\alpha\Delta x h_B/k+\beta_N^{"}}{1-\alpha_N^{"}+\frac{\alpha\Delta x}{k}}.$$

Sonli yechim algoritmi. Mashina algoritmi quyidagi qadamlardan iborat:

1. Tenglamalar tizimiga kiruvchi parametrlarning qiymatlarini va dastlabki qatlamdagi grunt suvlarining darajasi H_i^0 va bosimli suvlarining darajasini $h_{1i}^0, h_{2i}^0\ \ (i=1,2,...,N)$ kiritish.

2. Chegara shartlaridan $\alpha_0,\beta_0,\ \ \alpha_0^{'},\beta_0^{'},\ \ \alpha_0^{"},\beta_0^{"}$ progonka koeffitsientlarining dastlabki qiymatlarini aniqlash.

3. Parametrlarning qiymatlarini hisoblash, $A_i,B_i,C_i,F_i,\ A_i^{'},B_i^{'},C_i^{'},F_i^{'}\ A_i^{"},B_i^{"},C_i^{"},F_i^{"}$ uchta-diagonal chekli-ayirmalar tenglamalarini yechish.

4. $\alpha_i,\beta_i,\ \alpha_i^{'},\beta_i^{'},\ \alpha_i^{"},\beta_i^{"}\ \ (i=1,2,...,N-1)$. progonka koeffitsientlarining qiymatlarini hisoblash.

5. Chap chegarada funksiya qiymatini hisoblash: H_n, h_n, h_{2n}.

6. Funksiya qiymatini hisoblash: H_i, h_{1i}, $h_{2i}\ \ (i=0,1,2,...,N)$

7. Funksiya qiymatlarini jadval va grafik shaklida chiqarish: H_i, h_{1i}, h_{2i} $(i=0,1,2,...,N)$

8. Keyingi vaqt qatlamiga o‘tish. Shu bilan birga, olingan yechim keyingi vaqt qadamining dastlabki qiymati sifatida ishlatiladi.

9. Algoritmning 2-8 punktlari har bir vaqt qatlamida takrorlanadi.

ISSN 3030-3907

10. Masalaning yechimi tugatish.

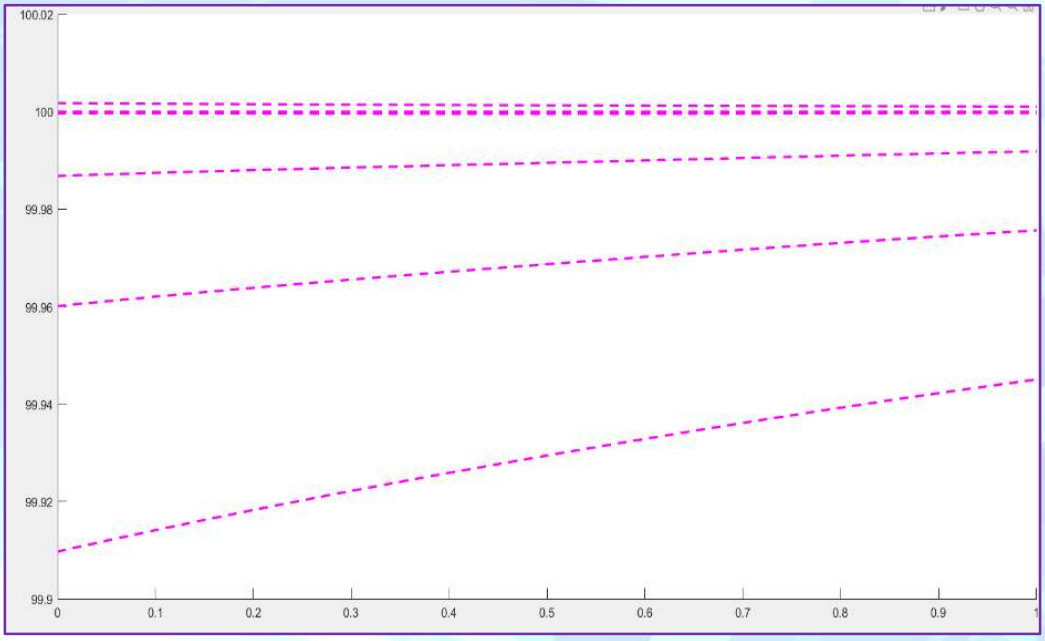
Matematik model va hisoblash algoritmi asosida dasturiy ta’minot ishlab chiqilgan bo‘lib, ushbu dasturlar yordamida ikki qatlamli va uch qatlamli suv tutuvchi qatlamlar modellari uchun gidrogeologik va melioratsion prognoz masalalari yechiladi, bu jarayonda grunt va bosimli suvlarning filtratsiya jarayoniga ta’sir qiluvchi barcha tabiiy va sun’iy omillar hisobga olinadi.

Hisoblash eksperimenti: uch qatlamli g‘ovak muhitda bosimli va bosimsiz suvlarning filtratsiyasini tahlil qilish va o‘rganish

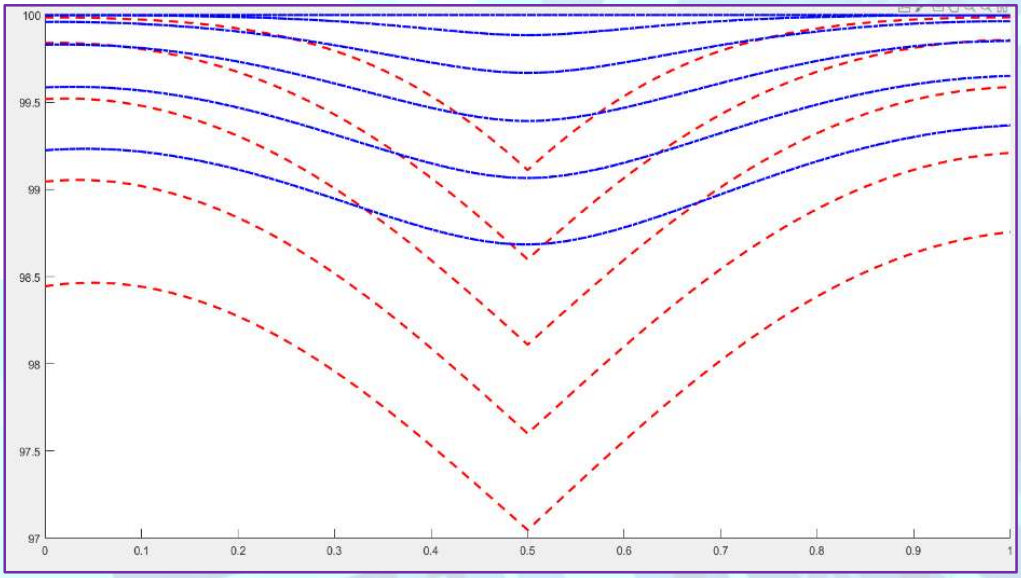
Sonli model asosida ikki dinamik ravishda bog‘langan qatlamlar tizimida bosimli filtratsiya (suv harakati) asosiy ko‘rsatkichlarini hisoblash uchun dasturiy ta’minot ishlab chiqilgan. Dasturiy ta’minot kirish ma’lumotlarini kiritish, ko‘rsatkichlarni hisoblash va natijalarni chiqarish bloklaridan iborat. Hisoblash natijalari grafik ko‘rinishda taqdim etilgan.

Turli qatlam parametrlariga va quduqlarning debitlariga oid hisoblash tajribalari o‘tkazilgan. Illyustratsiya sifatida bir qator masalalar uchun sonli yechimlar keltirilgan, quyidagi dastlabki ma'lumotlar bilan. Masalaning dastlabki ma'lumotlari quyidagilar: ikki qatlamning uzunligi teng: L = 1300 m, Hx – qatlamdagi dastlabki suv bosimi uchun xarakterli qiymat, 20 kg/m, K_1, K_2 – suv o‘tkazuvchanlik koeffitsientlari, 2 m/kun, K_p – yomon o‘tkazuvchi qatlamning koeffitsienti, 0,0005 m/kun, h_1, h_2 – qatlamlar qalinligi, mos ravishda 10 metr, μ – suv beruvchanlik koeffitsienti, 2, q – quduqning debit (oqim) qiymati, 100 m^3/kun, n – tarmoqli filtratsiya maydonining tugunlari soni, n = 41. Hisoblash tajribalari natijalari rasm 3.2 va rasm 3.3 da taqdim etilgan. Birinchi grafikda (rasm 3.2) grunt suvlarining darajasi o‘zgarishi ko‘rsatilgan, ikkinchi grafikda (rasm 3.3) yuqori va pastki qatlamlardagi bosimning taqsimlanishi ko‘rsatilgan. Natijalar shuni ko‘rsatadiki, yuqori qatlamning bosimi juda sekin kamaymoqda. Bu yuqori qatlamdan pastki qatlamga suv oqimi juda past ekanligini anglatadi, chunki suvning yomon o‘tkazuvchi qatlam orqali o‘tishi cheklangan.

ISSN 3030-3907



Rasm 3.2 - Suv horizontda sizot suvlarining o'zgarishi



Rasm-3.3 - Pastki va yuqori suv qatlamlarida bosimning o'zgarish dinamikasi

Ko‘p qatlamli bosimli va bosimsiz suvlar masalalarini yechish uchun ishlab chiqilgan yondashuvlar suv ta’minoti va sug‘orish sohalarida amaliy masalalarni yechishda qo‘llanilishi mumkin.

Xulosa

Xulosa qilib aytganda, ishlab chiqilgan matematik model, samarali hisoblash algoritmi va uning dasturiy ta’minoti asosan dinamik ravishda o‘zaro bog‘langan ko‘p qatlamli bosimli va bosimsiz suvlar darajasining o‘zgarishini tahlil qilish va prognoz qilish imkoniyatlarini ta’minlashga qaratilgan. Bu yer osti suvlarini ishlatishda juda muhim bo‘lib, ushbu yo‘nalishda turli xil masalalar sinfini yechishda katta yordam beradi.

ISSN 3030-3907

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